IOWA LIMESTONE PRODUCERS ASSOCIATION
NATIONAL STONE ASSOCIATION
RESEARCH PROGRAM

FINAL REPORT

CRUSHED STONE

GRANULAR SURFACING MATERIALS

NOVEMBER 30, 1990

ENGINEERING RESEARCH INSTITUTE
IOWA STATE UNIVERSITY ISU-ERI-AMES 90-411

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FINAL REPORT

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K.L. BERGESON
M.J. KANE
D.O. CALLEN

Sponsored by the

IOWA LIMESTONE PRODUCERS ASSOCIATION
and
NATIONAL STONE ASSOCIATION

In Cooperation with the

WEBSTER COUNTY ENGINEER
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"The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the Iowa Limestone Producers Association or the National Stone Association."

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INTRODUCTION

The following final report presents the results of research on the project for the period December 1, 1987 through November 30, 1990.

The research plan and work effort for the project involved the following tasks.

1. Preparation of a questionnaire and survey of all 99 Iowa county engineers for input on current surfacing material practice.
2. County survey data analysis and selection of surfacing materials gradations to be used for test road construction.
3. Solicitation of County engineers and stone producers for project participation.
4. Field inspection and selection of the test road.
5. Construction of test road using varying material gradations from a single source.
6. Field and laboratory testing and test road monitoring.

The project had initially been proposed as a two year project, but was extended to three years due to an unusually dry Iowa summer during the first year. The additional year was added so that test results would be representative of normal environmental conditions, and to expand the test result data base.

COUNTY ENGINEER SURVEY

In early December 1987, a survey questionnaire was developed relating to granular surfacing material practice. The draft questionnaire was reviewed and approved by Kenneth McNichols, Executive Director of the Iowa Limestone Producers Association (ILPA), and mailed to all 99 Iowa county engineers in late December. A sample letter to the County engineer and a copy of the questionnaire is given in Appendix A. The survey questionnaire was divided into four basic parts as follows:

I. New construction surfacing material practice
II. Existing road maintenance surfacing practice
III. Maintenance procedures and problems
IV. Subgrade soil influences

Eighty-six of the counties responded to the survey. A summary of the results and the raw data from the survey are given in Appendix B. The counties that did not respond were generally located in western Iowa where gravels are the primary surfacing material used. A summary of the data is as follows.

New Construction Surfacing Material Practice

Fifty-five (64 percent) of the reporting counties use crushed stone as a surfacing material in new construction. The Iowa Department of Transportation (IDOT) specifications are followed in 69 percent of the reporting counties. A phased application (64 percent) is preferred over a single application for new construction (36 percent). When a single application is applied to a new grade, the application rate ranges between 1250-2000 tons/mile depending on traffic count. The initial rate of application for phased construction is commonly 900-1500 tons/mile. A second application, the following year, is applied at a rate of 500-1000 tons/mile. These data obtained from this survey are compared to data obtained by Easley [1971] on Figures 1 and 2. Analysis of this indicates the total application (initial plus follow-up) is about the same. The current trend, however, is a lighter initial application and a heavier follow-up application. Surfacing material on newly constructed grades is compacted only by traffic. Crowns range from 4 - 8 inches on new grades, with 6 inches being the most common. Additional specifications for granular surfacing materials required by some of the counties apply to freeze-thaw loss, lowering the amount of material passing the #200 sieve, and abrasion loss.

Existing Road Surfacing Replenishment Practice

Replenishment application rates on existing stone roads is related to traffic count. When the traffic count increases from 0 - 200 vehicles per day (vpd) the replenishment rate rises from 150 to 425 tons/mile/year as shown in Figure 3. Frequency of application also varies with traffic count and averages once every 2 - 3 years. These data also compare reasonably well with that of Easley [1971]. Crushed limestone is being used as a replenishment material in 64 percent of the reporting counties. Stone is being used as a replenishment material primarily because of its availability, durability, and service history.

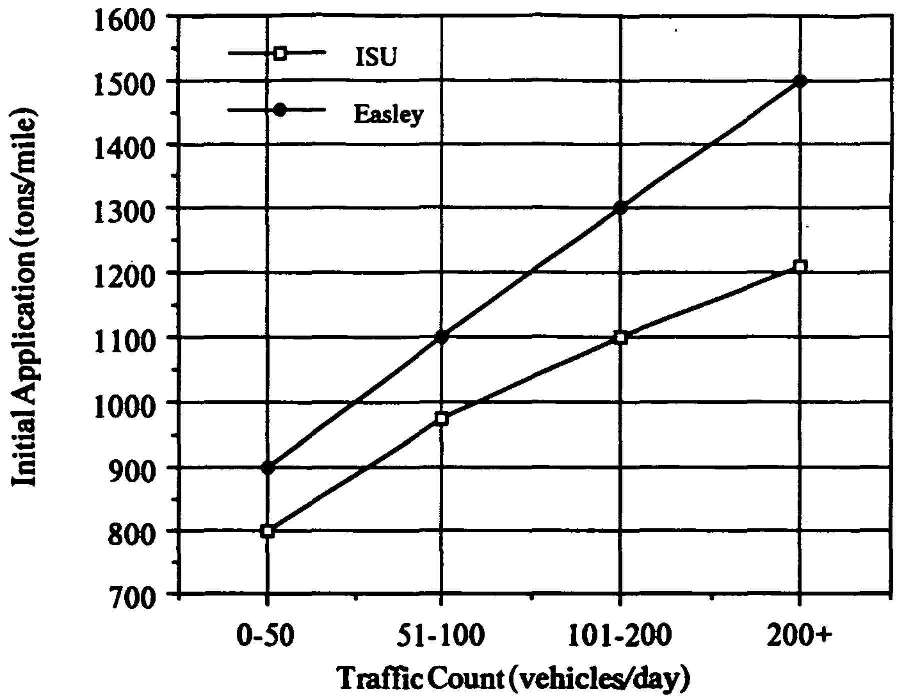


Figure 1. Initial Stone Application Rates for New Construction

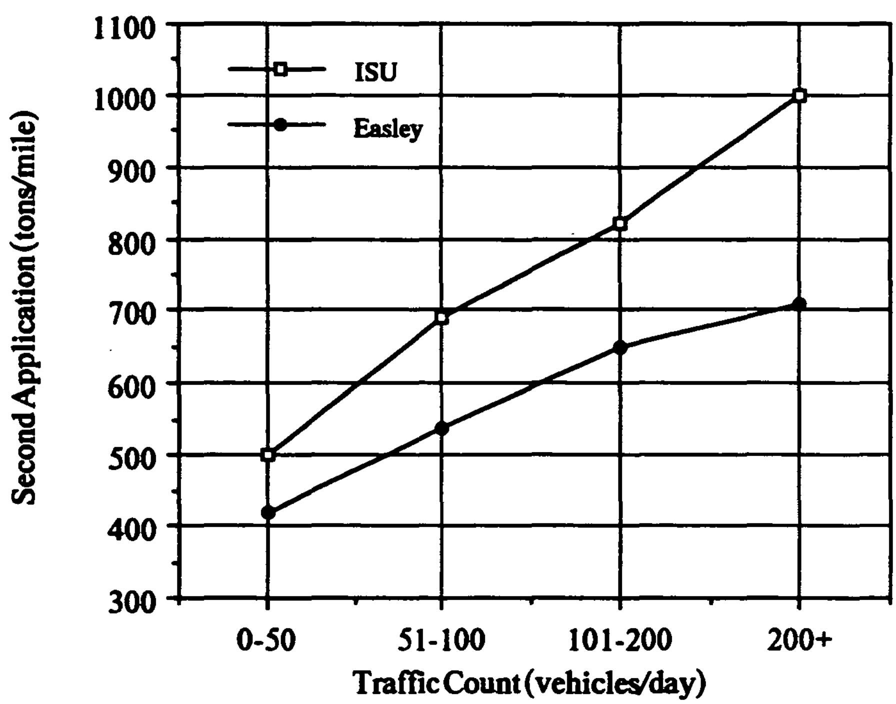


Figure 2. Follow-up Stone Application Rates for New Construction

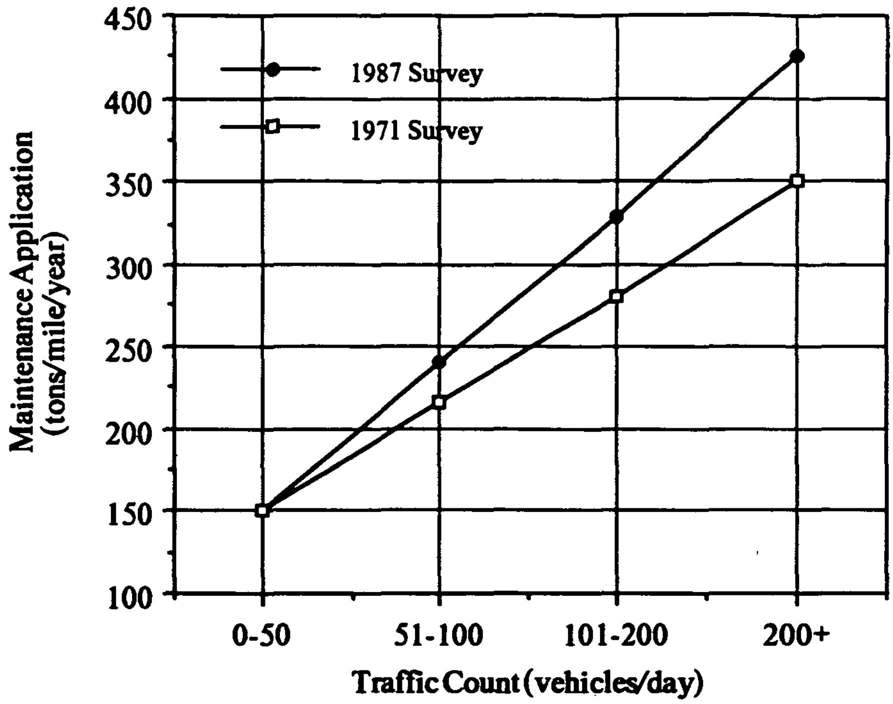


Figure 3. Iowa Granular Surfacing Maintenance Application Rates

Maintenance Procedures and Problems

County maintenance is a function of weather and traffic count. Grading is generally done once every two weeks depending on surface moisture and traffic count. The average traffic count on Iowa's secondary roads is 50-100 vpd. If traffic count is higher than about 150 vpd, the counties will increase their grading frequency to once every 7-10 days. The major problems reported by the county engineers concerning secondary roads are in order of priority: washboarding, potholing, material loss, rutting, dust, and subgrade intrusion. A dust palliation program is being used in 50 percent of the reporting counties. The most common treatment for dust is a calcium chloride application.

Subgrade Soil

A majority of the problems occurring on secondary roads are associated with a poorly drained subgrade. Soil subgrade types, however, are only considered by 56 percent of the counties as a design factor. Within the state, the most common subgrades soils are glacial tills and loess.

TEST ROAD

Test Road Selection

Based on crushed limestone source locations and the county engineers survey data, four counties were solicited by letter for interest in project participation. Iowa State University personnel met with the four engineers and inspected the potential test roads. Test road candidates were evaluated based on the following criteria.

- Road topography
- Traffic count
- Subgrade soil type
- Surfacing material source
- Distance from Ames
- County maintenance procedure

A road in Webster county best fit the project criteria and was approved for project use after field inspection with Robert Sperry, Webster county engineer and members of the ILPA Technical Committee. The road is located 4 miles north of US 169 and Iowa Highway 175. Test sections start 1/2 mile west of county highway P61. Figures 4 and 5 show the location of the test road.

This road was selected because it has a relatively flat topography with few trees and curves that could influence data collection. The test road also has very few residences along it so that traffic was relatively consistent over the test sections. Iowa Department of Transportation (IDOT) traffic count data obtained in January 1987, indicated about 70 vpd. The road has a relatively uniform cross section and similar subgrade soils throughout its length. It is within 40 miles of Ames and 15 miles from the Martin Marietta Fort Dodge mine stone source. Webster county also has a maintenance schedule similar to that used throughout the state. The road was constructed in the 1960's with gravel surfacing. A crushed stone surface was applied approximately five years ago.

Test Road Surfacing Gradations

Four gradations were proposed to be used on the test road. Gradation 1 was chosen since it was the finest gradation being used by an Iowa county. Similarly, the gradation used in section 4 was the coarsest being used. Target gradations for sections 2 and 3 were fit between the gradations for sections 1 and 4. IDOT Class A specifications, gradations of the existing test road surfacing

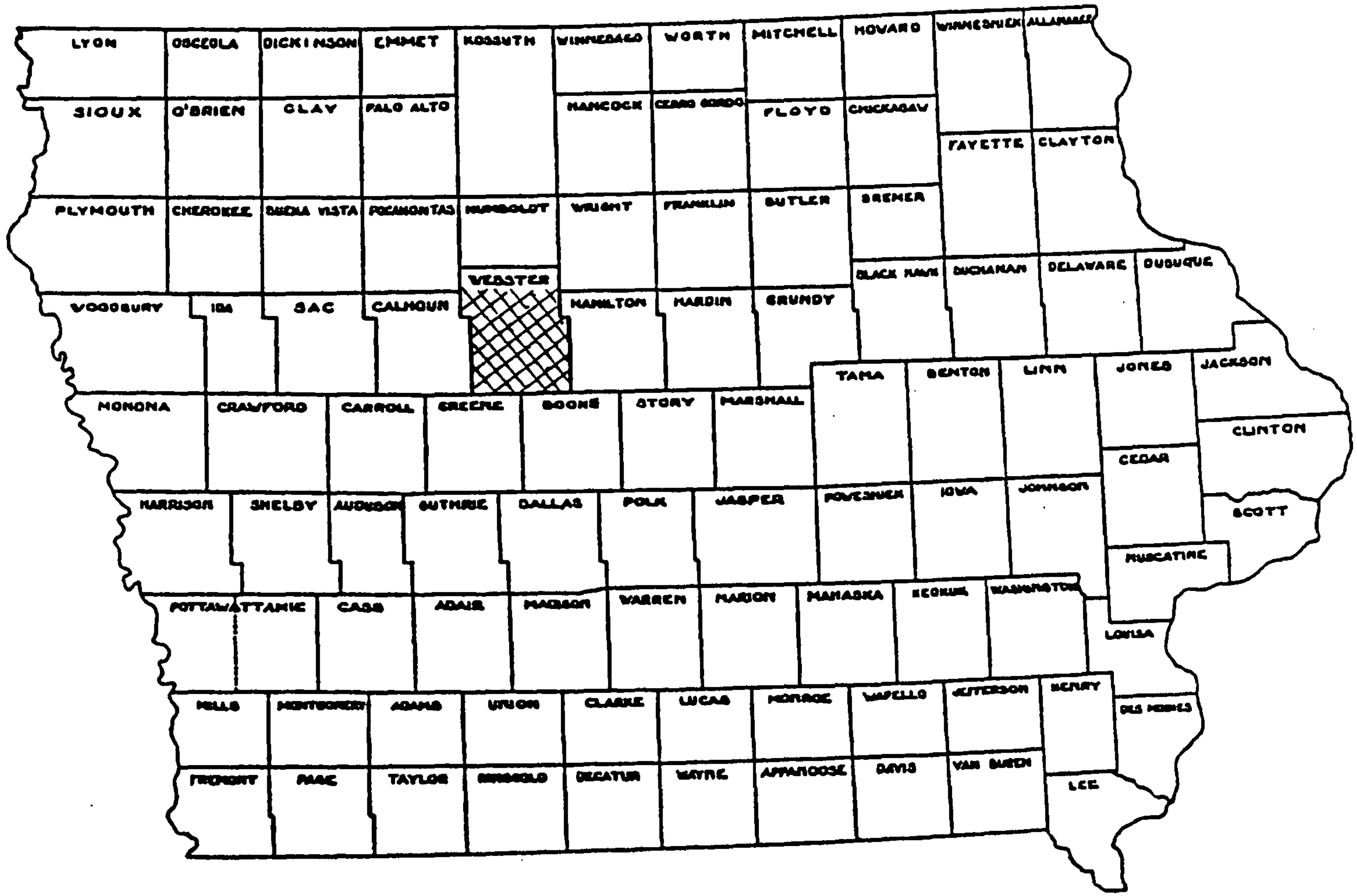


Figure 4. Test Road Location - Webster County

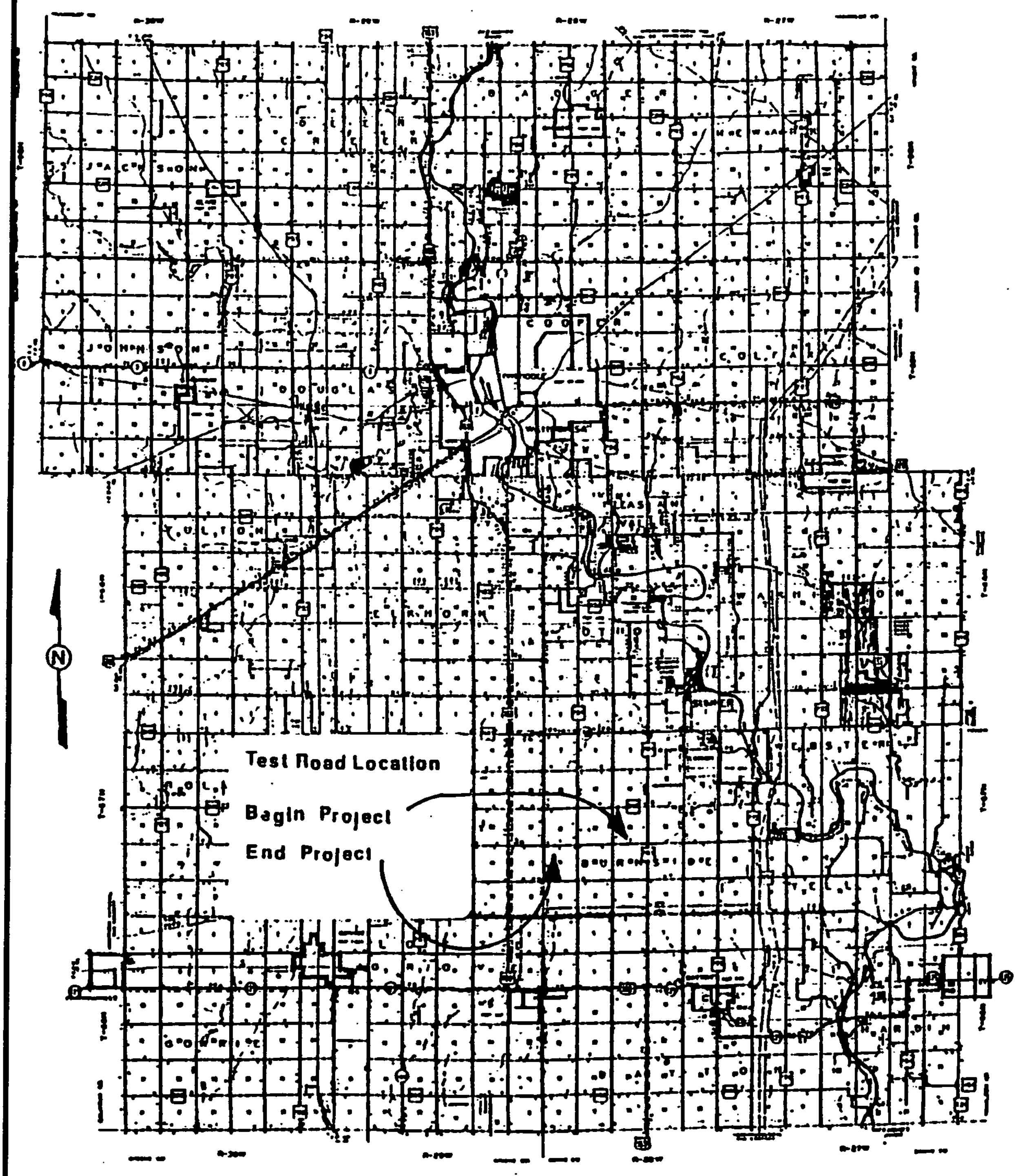


Figure 5. Test Road Location in Webster County, Iowa

material, along with target and "as constructed" surfacing material gradations are given in Table 1 as they were prior to December 15, 1987 (this specification has been changed).

Table 1. Test Road Gradations

Test Section Number	Sieve Size	IDOT Class A Spec's (% passing)	Existing[1] Road Surface Gradation (% passing)	Target[2] Blended Gradation (% passing)	As[3] Constructed Blended Gradation (% passing)
1	1"	100	100	100	100
	3/4"	-	93	100	97
	#4	20-75	31	58	64
	#8	20-40	16	40	40
	#200	-	1	11.5	12
2	1"	100	100	100	100
	3/4"	-	96	92	97
	#4	20-75	29	46	47
	#8	20-40	14	32	34
	#200	-	0	7.5	11
3	1"	100	100	100	100
	3/4"	-	92	96	97
	#4	20-75	43	35	42
	#8	20-40	25	20	25
	#200	-	0	4.5	7
4	1"	100	100	100	100
	3/4"	-	99	87	89
	#4	20-75	50	15	28
	#8	20-40	29	10	19
	#200	-	0	0	3

[1] Average of three samples taken from loose materials throughout the test road

[2] Target gradations were arrived at by mathematical blending of Martin Marietta gradation data of stockpiled materials at the Fort Dodge mine

[3] Average of three samples taken from loose surfacing material immediately after construction

Figure 6 shows the IDOT class A and B specification band graphically. Figure 7 shows the "as constructed" gradation test results graphically for each section. Test section designations relative to gradations and the IDOT specifications are as follows.

Section 1 — Fine section
Section 2 — Intermediate fine section
Section 3 — Intermediate coarse section
Section 4 — Coarse section

Test result discussions hereafter will refer to each test section by its gradation designation.

In order to produce the target gradations, it was necessary to blend materials from stockpiled stone at the Martin Marietta Fort Dodge mine. The physical properties of the stone are shown in Table 2.

Table 2. Crushed Stone Properties Martin Marietta Fort Dodge Mine (IDOT test data)

Date	Sample	Bed Location	Freeze-thaw Method A 16 cycle	Abrasion Grading B	Sp. G.	Abs. %
04/22/87	Production	36-42	1% loss	28% loss	2.656	1.02
09/01/87	Stockpile	36A-42	1% loss	26% loss	2.699	0.73

IDOT specifications for physical properties of Class A and B crushed stone are shown in Table 3. Comparison of test results to those given in Table 2 indicates the Fort Dodge mine stone easily meets the specifications.

For production considerations, the blends were designed primarily to meet the #8 sieve requirement. The gradation for the fine section 1 was created with a blend of 65 percent class A roadstone and 35 percent 3/8 inch minus. The intermediate fine section 2 was surfaced with straight class A roadstone. A blend of 60 percent class A roadstone and 40 percent 3/8 inch porous

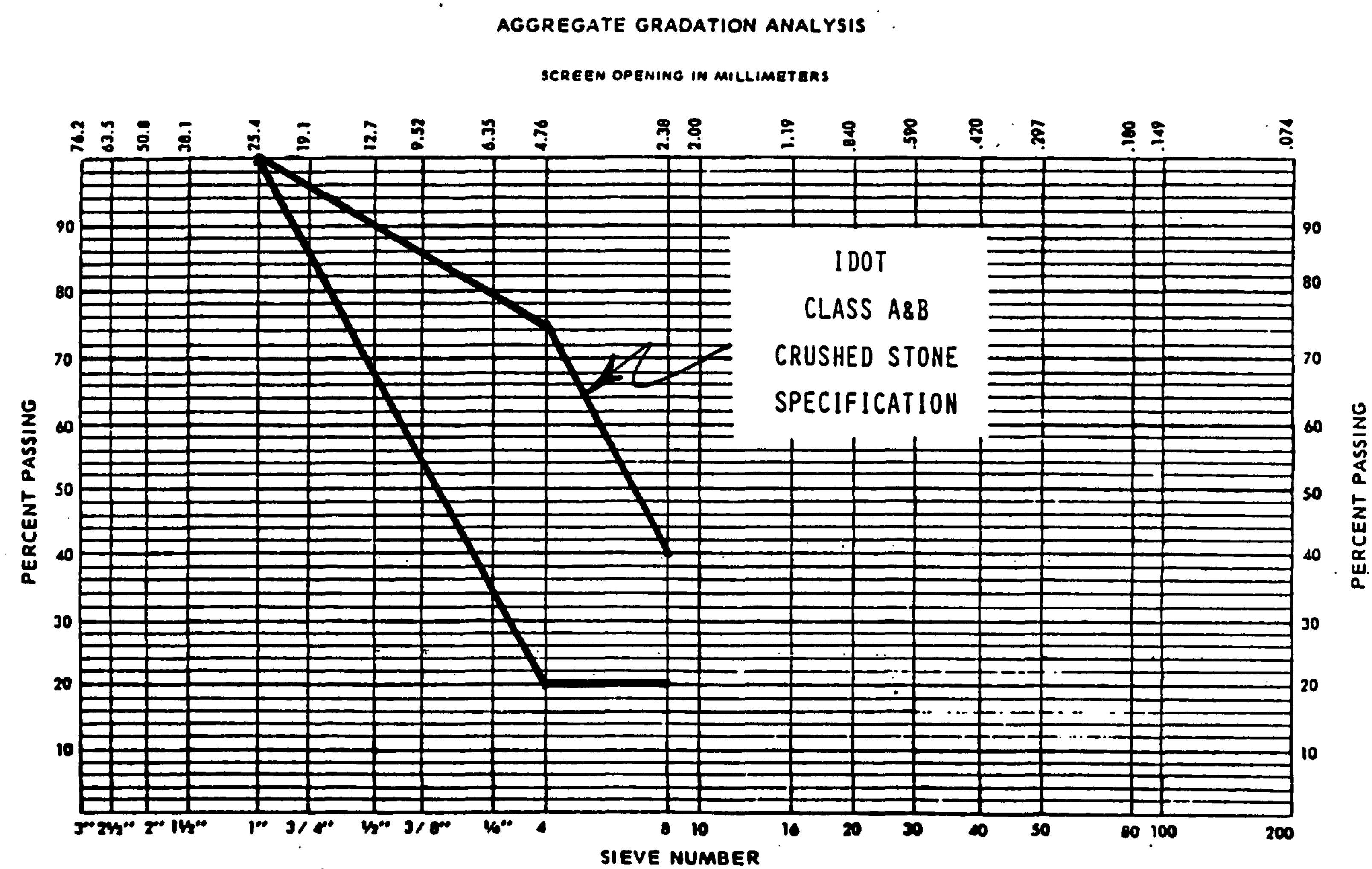


Figure 6. IDOT Crushed Stone Specification Prior to December 15, 1987

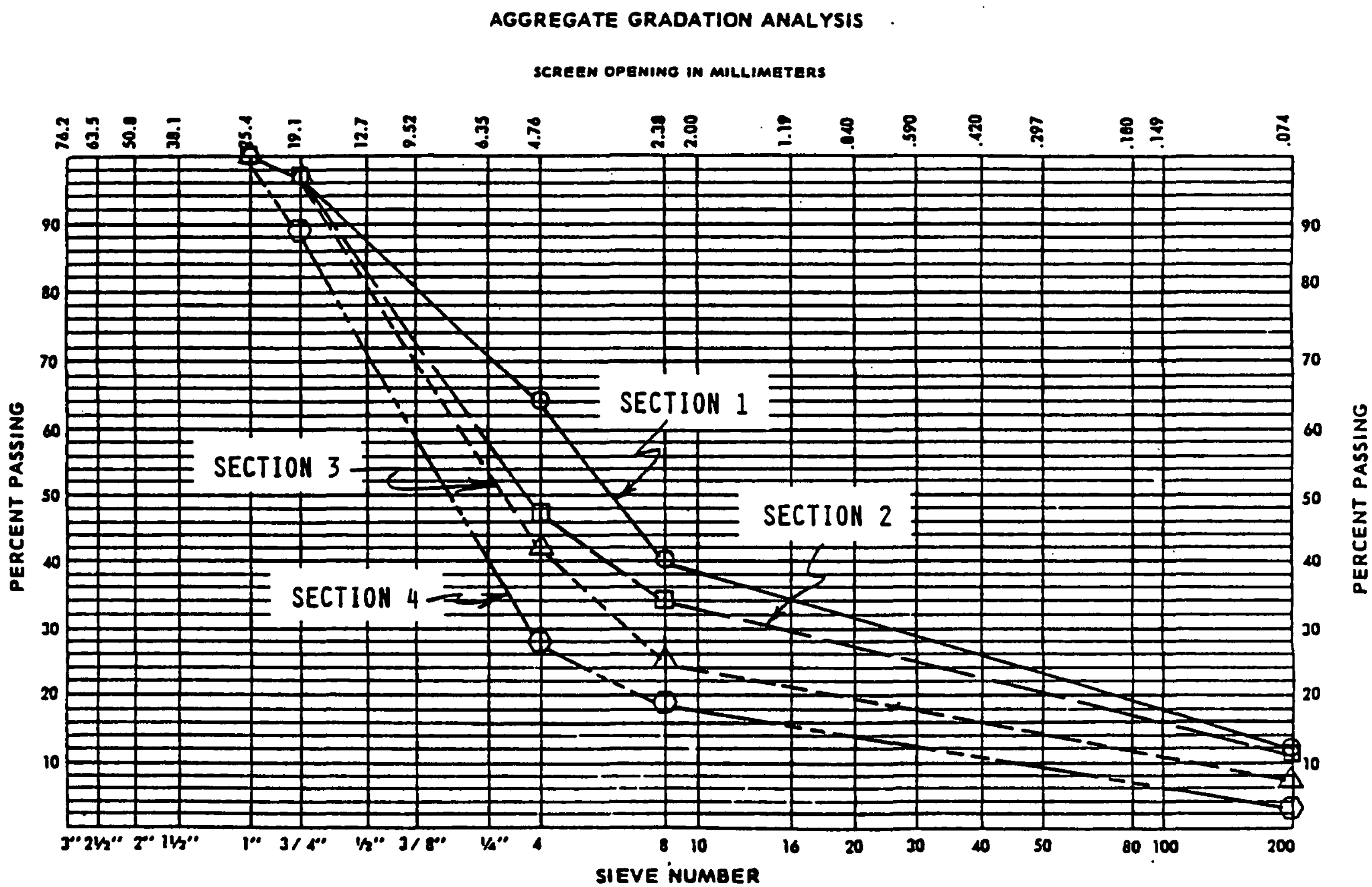


Figure 7. Test Road Surfacing Material Gradations "as constructed"

backfill was designed for the intermediate coarse section 3. The blend for the coarse section 4 used 70 percent 1 inch washed concrete stone and 30 percent class A roadstone.

Table 3. Iowa Department of Transportation Crushed Stone Specifications

Stone Class	Abrasion Loss AASHTO T96 Grading B (%)	Freeze-thaw Loss IDOT Test 211 Method C (%)	Freeze-thaw Loss Plus Abrasion Loss (%)	Mudballs (%)
A	45 max.	-	-	4 max.
B	55 max.	20 max.	65 max.	4 max.

<u>Test Road Construction</u>

Construction was started June 22, 1988 and was completed June 23, 1988. A replenishment rate of 400 tons/mile was selected corresponding to current application rates shown on Figure 3 and assuming a 2 year application interval. The rates of application for each 1/2 mile test section, in order to produce the target gradation, are listed in Table 4.

Prior to construction, Webster County personnel had prepared the test road by blading and removing all secondary ditches present at the shoulder line. Existing stone surfacing material was left in place and spread evenly over the road prior to new surfacing material applications.

The test road was constructed by Webster County personnel and equipment. Crushed materials were delivered to the site by County trucks. Construction of each test section was accomplished by end dumping of each material (while traveling) in the center of the road. Spread distances were calculated and measured off for each load. For sections requiring two materials to be blended, the second material was spread directly over the top of the first. Field mixing was accomplished by two motor graders working in tandem and tight blading the material back and forth across the road surface approximately 4 times. Field inspection and observations indicated thorough and adequate blending of materials which was verified by spot checking of surfacing material gradation samples

Table. 4 Material Blending and Application Rates for Each Half Mile Test Section

Section	Material	Amount (tons)
1	Class A Roadstone 3/8 inch minus	130 70
2	Class A Roadstone	200
3	Class A Roadstone 3/8 inch porous backfill	120 80
4	Class A Roadstone 1 inch washed concrete stone	60 140

obtained at the time of construction. Test road layout is shown on Figure 8. Results of the "as constructed" gradation tests on all sections are shown in Table 1 and graphically on Figure 7.

FIELD AND LABORATORY TESTING

General

Field and laboratory testing conducted for the project consisted of the following.

1. Subgrade soil testing to determine soil classification and in-place density/moisture properties.
2. Gradation testing to evaluate changes in surfacing materials particle size distribution.
3. Roughness testing to evaluate washboarding, potholing, and general rideability.
4. Braking tests to evaluate stopping distances and safety characteristics.

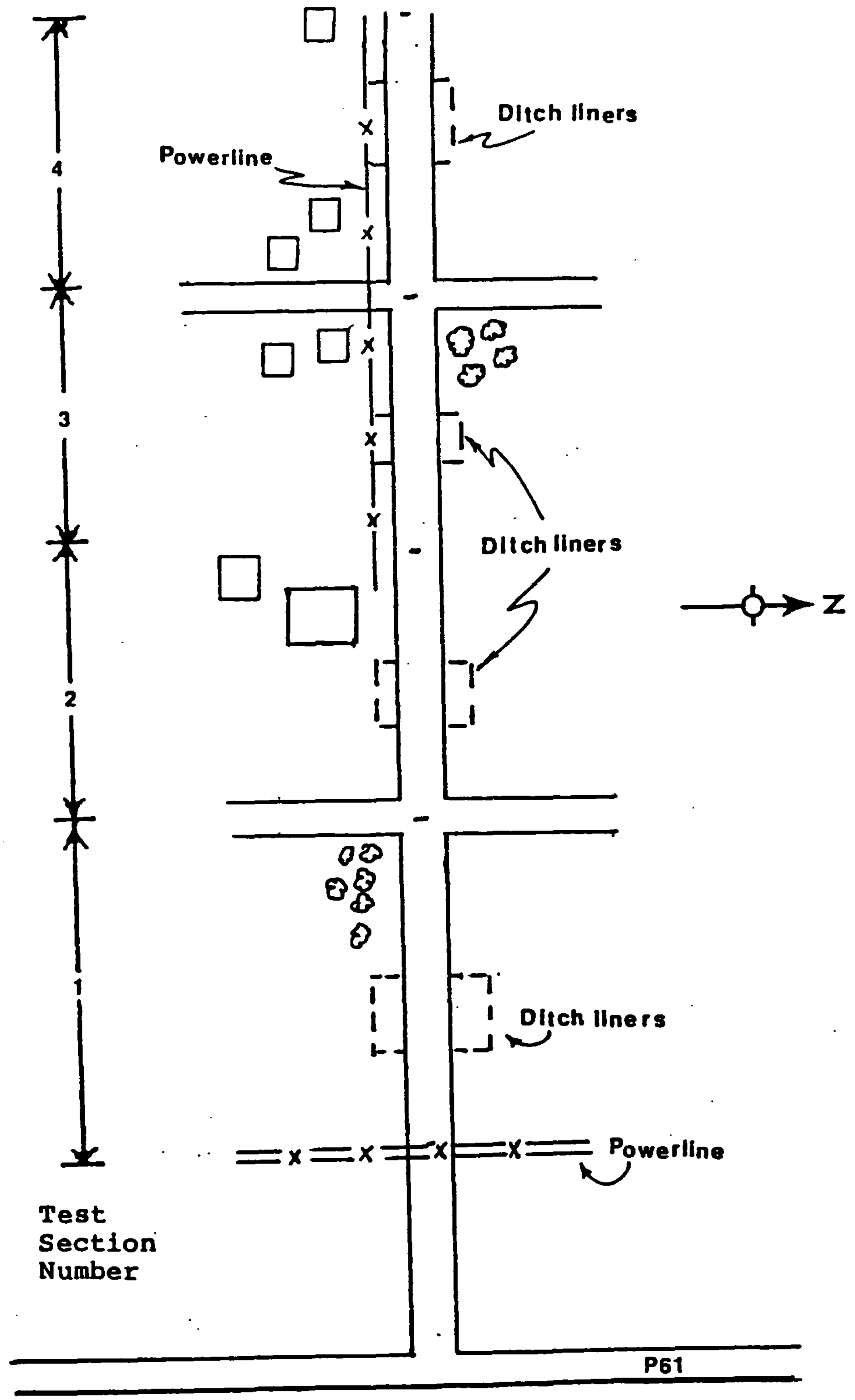


Figure 8. Test Road Layout

5. Stone throw-off testing to evaluate surfacing material loss from traffic.

6. Dust collection and testing to evaluate gradation influence on dust generation.

7. County maintenance personnel observations to evaluate maintenance and grading characteristics.

8. Subgrade intrusion observations to evaluate potential surfacing material loss.

Results of these tests are discussed in the following sections of the report.

Subgrade Soils

Subgrade soil samples were taken from the beginning, the middle, and the end of each test section in one foot depth increments up to three feet. Selected samples were tested for specific gravity, Atterberg limits, and grain size distribution by sieve and hydrometer analysis. Soils were then classified using the texturual, unified, and AASHTO classification methods. The results are given in Table 5 and indicate relatively uniform soils at an ML borderline CL classification (low plasticity) silts and clays. The AASHTO classifications were A-7-5 to A-7-6 soils, again indicating silty-clayey soils.

Subgrade density and moisture conditions were determined using a Campbell Pacific nuclear gauge. Two tests were conducted in each test section at depths ranging from 2 to 10 inches. Test results are shown in Table 6 and indicate average moisture contents ranging from 4.3 to 5.8 percent and dry densities ranging from 125 to 135 pounds per cubic foot. These data also indicate a relatively uniform subgrade condition.

Gradation Testing

Results of gradation testing of samples of loose surfacing materials obtained periodically after construction during the first year of service are shown on Figures 1 through 4 in Appendix C.

Table 5. Subgrade Soil Classification

Sample Number	Depth Ft.	Plastic Limit	Liquid Limit	Plastic Index	Specific Gravity	% Passing #10	% Passing #40	% Passing #200	Textural Classification	Unified Soil Classification	AASHTO Classification
1	1	34.5	48.6	14	2.61	96	83	73	Clay Loam	ML	A-7-6(14)
1	3	28.2	41.7	13	2.62	95	82	72	Clay Loam	ML	A-7-5(13)
3	1	29.6	45.9	16	2.61	98	89	65	Clay Loam	ML	A-7-5(11)
3	3	26.8	38.6	12	2.60	99	94	82	Clay Loam	ML	A-7-5(12)
5	1	30.7	46.0	15	2.60	94	79	61	Clay Loam	ML	A-7-6(08)
5	3	30.1	49.0	14	2.60	97	91	77	Clay Loam	ML	A-7-5(15)
8	1	30.3	45.0	15	2.62	93	84	59	Clay Loam	ML	A-7-5(08)
8	3	26.7	37.8	12	2.63	98	93	81	Clay Loam	ML	A-7-5(10)
9	1	26.3	41.7	15	2.62	91	79	69	Clay Loam	ML	A-7-5(10)
9	3	24.6	36.5	12	2.62	99	95	78	Clay Loam	ML	A-7-5(09)

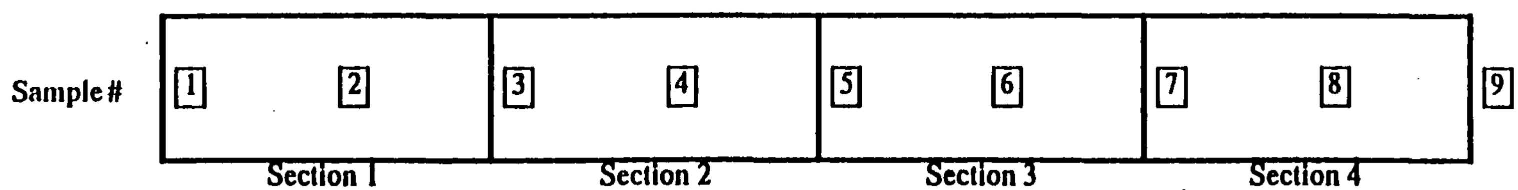
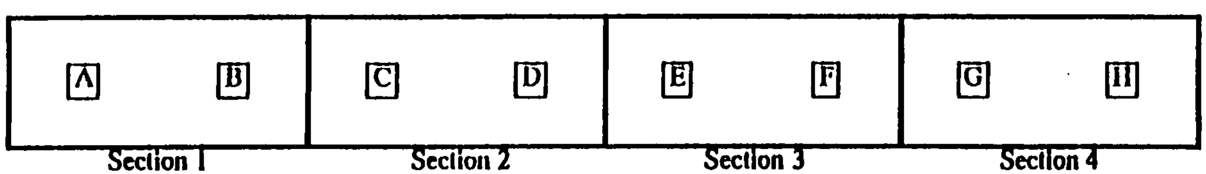


Table 6. Subgrade Density and Moisture

Section Number	Test Location	Test Depth, Inches: 2		4		8		10		Average	
		Moisture %	Dry Density pcf	Moisture %	Dry Density pcf	Moisture %	Dry Density pcf	Moisture %	Dry Density pcf	Moisture %	Dry Density pcf
1	A	4.3	133.6	4.1	138.4	4.2	139.0	4.4	132.6	4.3	135.9
1	B	3.6	137.3	3.4	138.6	3.5	136.2	3.7	133.0	3.6	136.3
2	A	5.1	125.7	5.2	125.8	5.3	126.5	5.5	122.5	5.3	125.1
2	B	4.7	138.0	4.7	132.3	4.6	135.3	4.7	133.0	4.7	134.7
3	A	4.8	138.8	4.7	135.8	4.8	137.6	4.9	133.8	4.8	136.5
3	B	5.1	134.5	5.0	133.4	5.1	133.7	5.1	129.7	5.1	132.8
4	A	5.9	122.2	5.7	126.8	5.7	127.8	5.9	123.3	5.8	125.0
4	B	5.1	134.5	5.0	133.4	5.1	133.7	5.1	129.7	5.1	132.8



Review of this data indicated, in general, a coarsening trend (#4 and #8 sizes) in the gradations of the loose surfacing material for all test sections. This coarsening trend was much more pronounced for the fine section 1, and the intermediate fine section 2 with the fine section exhibiting a 17 percent and 16 percent decrease in percent passing the #4 and #8 sieves respectfully. This is believed to be due to the fact that the fine section was developing a tight and thicker crust formation relative to the other sections. Attempts were made to measure crust thickness in the wheelpaths, but was highly subjective and test location dependent. Very approximate field measurements of crust thickness development, conducted during 1988, indicated rough average thickness of 1 to 2 inches for the fine section and down to approximately 1/2 inch for the coarse section 4. Other test sections exhibited intermediate values.

In addition to the thicker crust development of the fine sections, the coarsening trend may also have been due to coarse aggregate (plus #4) breakdown, due to traffic abrasion of loose materials in the coarser test sections 3 and 4 as indicated by the increase in percent passing the 3/4 inch sieves for those sections as indicated on Figures 3 and 4 in Appendix C.

Roughness Testing

Testing of surface wheelpath roughness during 1988 was accomplished using a Roughometer which is commonly used to measure pavement smoothness. Tests were conducted by Iowa Department of Transportation personnel using IDOT equipment. Test results are expressed as inches per mile of roughness and are shown graphically on Figure 9. Two tests were conducted on the test road at 105 and 124 days after construction.

Inspection of the data shown on Figure 9 indicated a strong trend of increasing roughness from the fine section 1 to the coarse section 4. The coarse section was 16 percent rougher than the fine section. The intermediate coarse section 3 was 6 percent rougher than the fine section. Again this is believed due principally to the tighter crust development exhibited by the finer gradations. Additional tests were not conducted due to scheduling problems with IDOT. From visual observation, and from driving on the test road, this trend remained evident during 1989 and 1990.

Braking Characteristics

All braking tests were accomplished using standard pickup trucks. Tests were conducted by locking the brakes while traveling at a constant speed of 25 mph. The braking distance was measured from the start of the skid marks to the front axle of the truck. Tests were conducted both

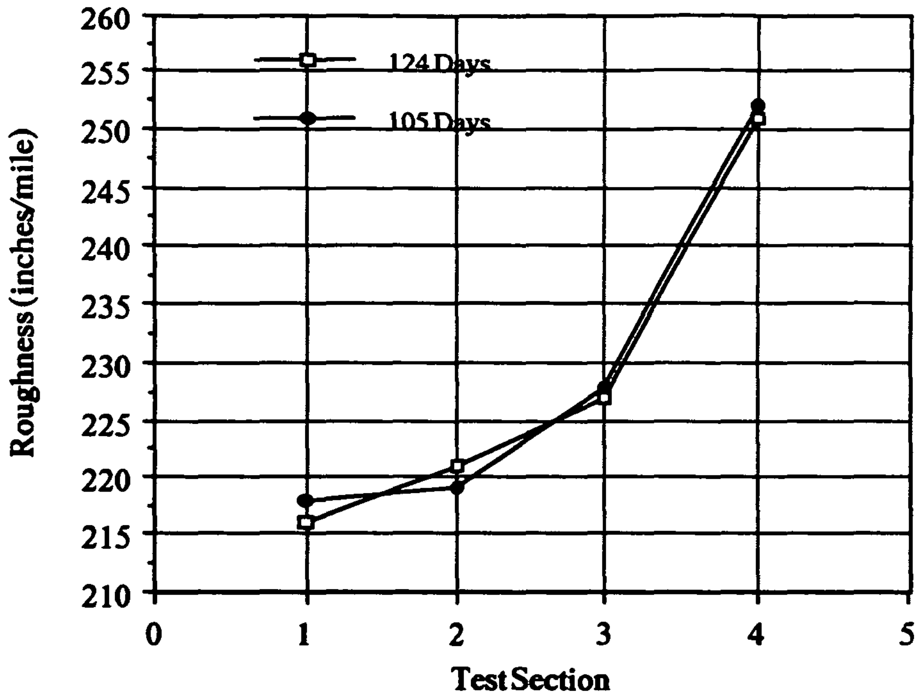


Figure 9. IDOT Roughometer Test Results

in and out of the wheelpaths and under both wet and dry surface conditions periodically from June 1988 through September 1990. All test data is shown in graphical form in Appendix D. Results for test conducted under normal (dry) and wet conditions, averaged over the entire two year test period, are given on Figures 10 and 11. Each set of test data were normalized to section one to minimize operator and vehicle variability of test results.

For wheelpath test data shown in Figure 10 (for dry condition), there is a slight trend of increased stopping distance required with increased coarseness of the surfacing material. This trend was much more evident in the test data during the first summer when there was an abundance of surfacing material present. Figure 11 presents results of braking data under wet surface conditions. Since the number of tests is small, results are not statistically significant but do indicate an increased stopping distance required compared to the fine section. Again, these test results are indicative of the importance of the fine fraction acting to promote a good crust development which in turn increases tire contact area for better braking under dry or wet conditions.

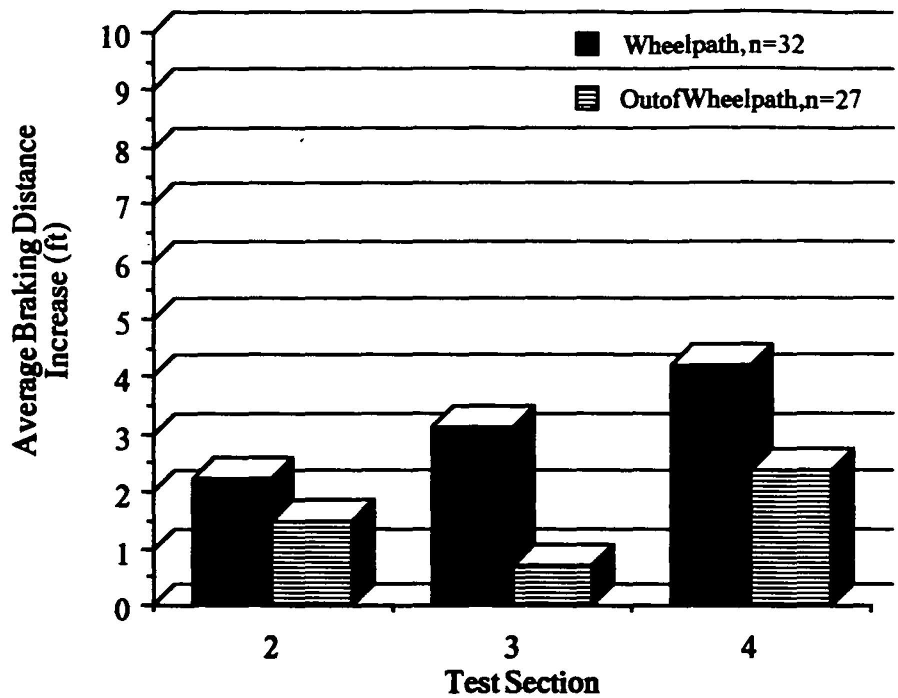


Figure 10. Average Dry Braking Distances Relative to Section One

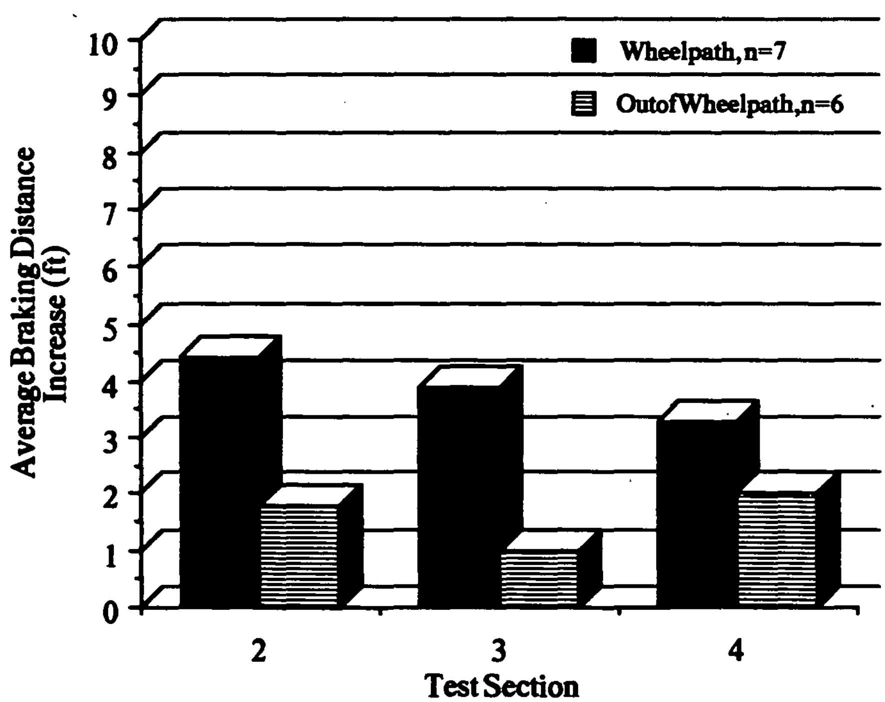


Figure 11. Average Wet Braking Distances Relative to Section One

Aggregate Throw-Off

Ditch liners were constructed of four millimeter thick plastic material 100 feet long and 50 feet wide. They were installed in both ditches at the approximate center of each test section. The perimeter of the plastic liners were anchored in an eight-inch deep trench and held in place with backfilled soil. The upper edge of the liner was installed at the road shoulder line and extended through the ditch to the toe of the backslope. A one foot high backboard was installed in the trench at the backslope to prevent material loss.

Throw-off testing was initiated on August 11, 1988. The aggregate collected in the liners was removed on September 6, October 4, and October 21, 1988. Samples were returned to the laboratory and scalped over a #8 sieve to remove blown in field and road silts, sands, and dust. The remaining material was weighed and sieved. The results of the gradation analyses are shown on Figures 1 through 4 in Appendix E. Results indicated this throw-off material to be composed of 10 to 15 percent plus 3/4 inch material, 40 to 60 percent 3/8 inch to 3/4 inch material, and 30 to 50 percent #8 to 3/8 inch size material. Figure 12 presents the results of the three throw-off surfacing material collection tests conducted during the summer and fall of 1988. These data have been estimated as the projected potential loss assuming a traffic count of 70 vpd for the test road, and that the loss during winter from traffic and snow removal is equivalent. From Figure 12 the losses from all sections are estimated to range from about 0.10 to 0.20 tons/mile/vehicle/year. For a 70 vpd road this is equivalent to between 7 and 14 tons/mile/year throw-off loss. Due to the limited data set, no conclusions can be definitively drawn relative to the influence of gradation on surfacing material loss.

The plastic liners deteriorated severely during the winter of 1988, and were reinstalled during the summers of 1989 and 1990, but again deteriorated quickly due to weather and vandalism. The data that was collected, therefore, was sporadic and accurate comparison between test sections was impossible. The project budget did not allow for a higher quality ditch liner construction.

Dust Generation

Dust testing was conducted using two high-volume stationary air samplers manufactured by General Metal Works Corporation. A gas generator was used to power the vacuum motors of the samplers. The samplers function by drawing in high-volumes of dust-laden air through a filter paper medium which traps the dust particles. Dust testing was conducted in the center of each test section by setting a sampler at the edge of each shoulder. One test consisted of 10 passes of a

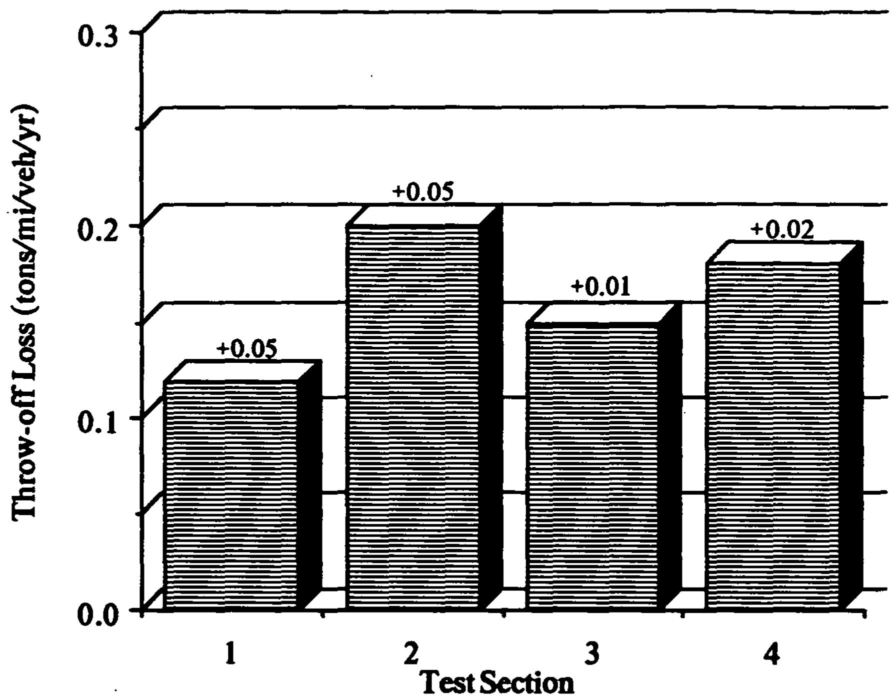


Figure 12. Aggregate Loss Due to Throw-Off

standard pick-up truck between the samplers at a speed of 40-45 mph. The filter paper was removed from each sampler and sealed in the field prior to returning to the laboratory for testing.

Testing was conducted periodically on the project from June, 1988, through the end of September 1990. Tests were conducted over a wide variety of surface material conditions, including moisture, amount of material present, and various stages of maintenance. In addition, the summer of 1988 was unusually dry, the summer of 1989 was normal, and the summer of 1990 was unusually wet. The results therefore are representative of a wide range of environmental service conditions. Dust generation test data were normalized to test section one (fine section) for each set of test data in order to minimize the influence of test and environmental variations. Testing was conducted both in and out of the wheelpaths.

The results of all dust testing is shown in graphical form in Appendix F. Figure 13 presents the average of all test results. Interestingly, all test sections exhibited increased dust generation for both in and out of the wheelpaths compared to the fine section. The test data shows 10 to 40 percent more dust generated in the wheelpaths and 20 to 60 percent more dust out of the wheelpaths for the other sections. Out of the wheelpath dust generation was expected to be higher

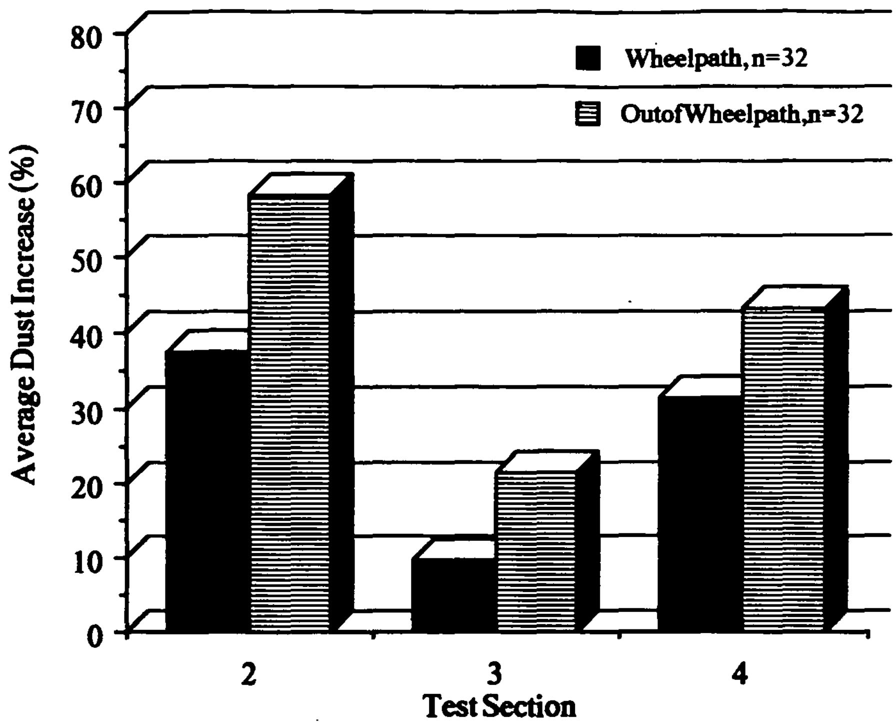


Figure 13. Average Dust Generation Relative to Section One

because of the loose uncompacted material present. The intermediate fine section exhibited the highest values compared to section one. This may be due to the combination of a low amount of minus No. 4 material and a relatively high amount of minus No. 200 material present in section two. Wheelpath crust development was not as evident in this section as was in section one. What is important, however, is that the fine gradation section generated considerably less dust than all of the other sections. It has been the misconception of many engineers that if crushed stone surfacing with a high amount of fines is used then dust generation will be higher. Instead, the use of a well-graded material with adequate fines promotes the formation of a tight surface crust which acts to reduce the dust generation.

County Maintenance Observations

Discussions with Webster County test road maintenance personnel and with local residents are generally summarized as follows.

- The coarse section 4 was difficult to blade because it was hard to carry the material for any distance. The fine section 1 and the intermediate fine section 2 were easiest to blade and maintain.

- The coarse section 4 was prone to developing washboarding.
- Vehicle handling was poor on the coarse section 4.
- Trailers tended to fishtail severely on the coarse section 4.

Subgrade Intrusion

Visual observation of the test road over the 2 1/2 year test period did not indicate any discernible difference in subgrade intrusion characteristics. Test holes dug through the surface for soil testing and for crust measurements did not appear to indicate any significant differences between test sections. Very little aggregate was noted in the subgrade below the crust in any of the sections.

DISCUSSION

Past research conducted at Iowa State University [2,3] indicated that the loss from dust generation on Iowa secondary roads is on the order of one ton per mile per vehicle per year. For a road with 70 vpd, this would amount to 70 tons per year lost to airborne dust. The throw-off loss data from this project, about 0.15 ton per mile per vehicle per year, yields about another 10 tons per mile lost at 70 vpd. This totals approximately 80 tons per mile lost per year for both dust generation and throw-off. Over a two-year period this would amount to about 160 tons and for a three year period about 240 tons lost. From Figure 3 the maintenance surfacing requirement for a normal 70 vpd road would be about 230 tons per mile every two to three years; therefore, estimated losses from dust and aggregate throw-off are roughly equivalent to the maintenance surfacing requirement. This project required maintenance surfacing (except for the test sections) after two years of service.

Recent research conducted by Riverson et al. [4] on a study of stone and gravel roads in Indiana indicated the importance of surfacing material gradation properties. They found a strong correlation between roughness and rut depth and the percent passing the No. 10, and No. 200 sieves. The binding properties of these materials was important. Their research also indicated that stone above 1 inch in maximum size may not be conducive to crust formation.

CONCLUSIONS

The results of this research project indicate that crushed stone surfacing material graded on the fine side of IDOT Class A surfacing specifications provides lower roughness and better rideability; better braking and handling characteristics; and less dust generation than the coarser gradations. This is believed to be because there is sufficient fines (-#40 to - #200) available to act as a binder for the coarser material, which in turn promotes the formation of tight surface crust. This crust acts to provide a smooth riding surface, reduces dust generation, and improves vehicle braking and handling characteristics.

ACKNOWLEDGEMENTS

This research project has been supported by a research grant from the National Stone Association and the Iowa Limestones Producers Association. The cooperation and assistance of the Webster County engineer and the board of supervisors, the staff of Martin Marietta at the Fort Dodge Mine, and the Iowa Department of Transportation personnel is gratefully acknowledged.

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APPENDIX A

COUNTY ENGINEER SURVEY QUESTIONNAIRE

IOWA STATE UNIVERSITY

Department of Civil and
Construction Engineering
Ames, Iowa 50011-3232

Telephone: 515-294-2140

December 11, 1987

Mr. Donald J. Lynam
Adair County Engineer
P.O. Box 196
Greenfield, IA 50849

Dear Don,

Within the past month, the Civil Engineering Department at Iowa State University has received a research grant from the Iowa Limestone Producers Association and the National Stone Association. The purpose of this grant is to conduct a two year research project directed at evaluating the field performances of various gradations of crushed stone granular surfacing materials. In order to best determine which gradations and materials will be field tested, your help is needed and would be appreciated.

Enclosed with this letter is a questionnaire. We sincerely hope that you could take some time out of your busy schedule to fill out this survey, and return it to us in the enclosed envelope. This data will be used in formulating test road gradation and materials sections. A prompt response would be appreciated, so that the construction planning phase of this project could be initiated. Your cooperation on this project would be a benefit to the research project, as well as to your future application of crushed stone as a surfacing material.

If we can be of any assistance to you as you complete the survey, please contact us. Once again, we would like to thank you for taking the time to complete the questionnaire, and for helping to make this project a successful one.

Sincerely,

Michael J. Kane
Graduate Research Assistant
515-294-8767

Kenneth L. Bergeson, P.E.
Research Program Manager
515-294-9470

MK/KGB:aw
Enclosure:

ILPA/ISU GRANULAR SURFACING MATERIAL RESEARCH PROJECT SURVEY DECEMBER 1987

NEW CONSTRUCTION

1. Are IDOT specifications for granular surfacing material followed? If not, what specifications are used?

2. If so, what type and class of material is specified (gravel- B or C or stone A, B, or C)?

3. Why do you specify this type and class?

4. Are any additional specifications imposed (gradation, plasticity index, minus #200 other)?

5. How many miles of new surfacing for 1988? ____________ mi.

6. What is your application rate (tons/mile) for new construction? Is this a single application or phased application?

7. From what source(s) are materials obtained?

8. What crown is designed for new construction?

9. Is the surfacing material compacted on application? If so, how?

10. What is the average or range of daily traffic count on roads proposed for construction?

EXISTING ROADS

1. How many miles of existing surfaced roads are maintained in your county?

2. What is your average or range of application rate for replenishment of granular surfacing materials? Does this vary with traffic count?

3. Are IDOT specifications for granular surfacing materials followed? If not what specifications are used?

4. If so, what type and class of material is specified (gravel- B or C or stone A, B or C)?

5. Why do you specify this type and class?

6. Are any additional specifications imposed (gradation, plasticity index, minus *200, other)?

7. From what source(s) are materials obtained?

8. Is replenishment material compacted other than by traffic?

9. What would you estimate the average or range of crown to be on existing roads?

MAINTENANCE PRACTICE

1. What primary factor(s) dictates the frequency of grading (traffic count, weather, materials, etc.)?

2. What is the average and/or range of normal grading operations (for example, once each 10 days)?

3. In your opinion how would you rank the following problems in order of severity?

Washboarding	______
Potholing	______
Rutting	______
Dust generation	______
Subgrade intrusion	______
Surfacing material loss	______
other ______________	______
other ______________	______

4. Do you have a dust palliation program in your county? Approximately how many miles? What type (CaCl, water, oil, etc.)?

GENERAL

1. What is the predominant soil subgrade type in your county (glacial till, loess, etc.)?

2. Do you consider the subgrade soil to be a significant factor in your replenishment schedule or grading practice? If so, why?

APPENDIX B

SURVEY DATA SUMMARY AND RAW DATA

COUNTY PARTICIPATION SUMMARY AND STATISTICS

1. 86 counties participated.
2. 55 use crushed stone, 28 use gravel.
3. 59 follow IDOT specifications.
4. 55 use a phased application, 29 apply the material with a single application.
5. 21 of the single application counties apply the material at a rate between 1250-2000 tons/mile.
6. First applications are usually in the area of 750-1250 tons/mile.
7. Second application is commonly 500-1000 tons/mile.
8. Most roads are not compacted.
9. Crowns are usually 4-8 inches high.
10. An average traffic count is between 50-150 vehicles/day.
11. Most counties that require additional specifications do so to control the amount of fines, freeze-thaw and abrasion.
12. Stone replenishment is a function of the traffic count.
13. The amount used to replenish is from 100-500 tons/mile.
14. Generaly stone is used for its ease of production, history, and durability.
15. Grading is a primarily a function of weather and the traffic count.
16. Grading usually is done once every two weeks.
17. Clays, silty-clays, and silts are the most frequently encountered soil subgrades.
18. 49 of the counties do not use soil type as a design factor.
19. 34 counties do use soil type as a design variable.
20. Most subgrade problems are do to poor drainage.
21. Half of the counties do have some form of a dust program.
22. CaCl is generally the treatment used.
23. Washboarding is the biggest problem, followed by potholing ,material loss, rutting, dust, and subgrade intrusion.

NEW CONSTRUCTION

ARE DOT SPECS FOLLOWED?

YES	59
NO (4)	20
MAYBE	7

MATR'L CLASS

STONE		
	A	40
	B	1
	C	0
	D	14
GRAVEL		
	A	0
	B	16
	C	12

NEW SURFACING MILES

0-2	28
2-4	17
4-6	15
6-8	6
8-10	6
10-12	7
12-14	2
14-16	0
16-18	1
18-20	0
20<	5

PHASED APPLICATION

YES	55
NO	29
MAYBE	3

SINGLE

0-250	
250-500	1
500-750	5
750-1000	2
1000-1250	3
1250-1500	9
1500<	12

PHASED

	1	2	3
0-250	1	2	1
250-500	6	8	2
500-750	10	17	
750-1000	22	17	
1000-1250	10	5	
1250-1500	3	3	
1500<	2	2	

COMPACTION

YES		1
NO		83
MAYBE		3
TYPE:	SHEEPS	2
	RUBBER	1

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CROWN	
0-2	0
2-4	1
4-6	22
6-8	52
8-10	6
10-12	1
12<	2

TRAFFIC COUNTS	
0-50	17
50-100	36
100-150	25
150-200	15
200<	17

WHY SPECF'D

		STONE	GRAVEL
A	HISTORY	6	0
	FIT NEEDS	4	0
	LOW FINES	2	0
	PROD.	12	0
	GRAD.	4	0
	COST	5	0
	TEXTURE	6	0
	DURABILITY	6	0
B	HISTORY	0	1
	FIT NEEDS	0	2
	LOW FINES	0	3
	PROD.	1	7
	GRAD.	0	0
	COST	0	3
	TEXTURE	0	1
	DURABILITY	0	1
C	HISTORY	0	1
	FIT NEEDS	0	2
	LOW FINES	0	1
	PROD.	0	8
	GRAD.	0	0
	COST	0	1
	TEXTURE	0	1
	DURABILITY	0	0
D	HISTORY	1	
	FIT NEEDS	1	
	LOW FINES	5	
	PROD.	4	
	GRAD.	1	
	COST	3	
	TEXTURE	1	
	DURABILITY	1	

/0[illegible]5

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ADD. SPECS

1 CRUSHED STONE 1 1/4" CRUSHER RUN
2 WANT LESS 200 THAN ALLOWED
3 GRAVEL MODIFIED #200 0-7%
4 KEEP % PASING #8 REASONABLE
5 ABRASION <50%, #8 15-30%
6 MAX. 8% - 200 AT MONTOUR
7 ABRASION <45%, FREEZE THAW <15%
8 ABRASION <45%, SOUNDNESS <10%
9 MUDBALLS <4%
10 #8 18-28%
11 WANT LOW FINES
12 MIN. 7% CRUSHED PARTICLES
13 AMOUNT OF CLAY IS RESTRICTED
14 1 1/8" TOP SIZE, <#8 SCREENED OUT
15 3/4" MINUS AS CRUSHED FROM CLAY CO. PIT
16 USE AS IS FROM COUNTY PIT
17 CONTROL % PASSING #8 SIEVE
18 GRACATION ON CLASS D STONE #24
18 MUDBALLS <4%, FREEZE-THAW <15%
19 1" MAX. SIZE, MUDBALLS <4%, ABRASION <45%
19 FREEZE-THAW <15%, #8 20-40%
20 STONE "A" MODIFIED TO GRADATION #25
21 CLASS D REDUCE THE AMOUNT PASSING #200
22 CLASS A WITH, 3/8" 100%, #8 <35%
23 1" MODIFIED
24
25
26
27
28
29
30
31
32

/015

/015

ADD. GRADS.

	SIEVE	% PASSING
1.		
	1"	100%
	3/8"	40-75%
	4#	25-60%
	#10	15-45%
	#200	3-12%
2.		
	1"	100%
	3/4"	75%
	1/2"	50-75%
	#4	20-30%
	#8	10-20%
3.		
	1"	100%
	3/4'	85-95%
	#4	<75%
	#8	15-30%
4.		
	1"	100%
	#4	<75%
	#8	10-25%
5.		
	1 1/4"	100%
	1"	90-100%
	3/4"	70-90%
	3/8"	50-70%
	#4	30-60%
	#8	15-30%
	#200	5-12%
6.		
	1"	100%
	#4	20-75%
	#8	15-30%
	#200	<4%
7.		
	1"	100%
	#8	12-18%
8.		
	#4	50%
	#8	40%
9.		
	3/4"	100%
	#4	25-65%
	#8	30%
	#200	<4%
10.		
	1 1/4"	100%
	1"	95-100%
	3/8"	<50%
	#8	10-20%
	#200	0-15%
11.		
	#4	60%
	#8	30%
	#200	6%
12.		
	1"	100%
	3/4"	85-95%
	#4	20-50%
	#8	20-40%
13.		
	3/4""	100%
	#4	<60%
	#8	<40%
	#200	<15%
14.		
	1 1/4"	100%
	1"	90-100%
	3/4"	75-90%
	#4	35-65%
	#8	<40%
15.		
	1 1/4"	100%
	1"	95-100%
	#4	<45%
	#8	<30%
16.		
	1"	90-100%
	#4	0-55%
	#8	0-30%
	#200	0-12%
17.		
	3/4"	75%
	1/2"	50-75%
	#4	20-30%
	#8	10-20%
18.		
	1"	90-100%
	#4	30-60%
	#200	5-12%
19.		
	1"	100%
	3/4"	75-95%
	#4	25-65%
	#8	30%
20.		
	1"	90-100%
	3/4"	75-90%
	#4	35-65%
	#8	<40%
21.		
	1"	95-100%
	#4	45%
	#8	<30%
22.		
	1"	95-100%
	3/8"	<50%
	#8	10-20%
	#200	<15%
23.		
	1 1/4"	100%
	#8	15%
24.		
	1 1/2"	100%
	1"	98%
	#8	35%

EXISTING ROADS

ARE DOT SPECS FOLLOWED?

YES	57
NO (4)	21
MAYBE	8

MATR'L CLASS

STONE		
	A	40
	B	2
	C	0
	D	14
GRAVEL		
	A	0
	B	16
	C	3

EXISTING MILES

0-100	0
100-200	0
200-300	0
300-400	1
400-500	4
500-600	17
600-700	16
700-800	18
800-900	17
900<	11

REPLENISHMENT RATE

0-100	8
100-200	22
200-300	22
300-400	26
400-500	21
500-600	9
600<	6

VARY TRAFFIC COUNT

YES	59
NO	14

COMPACTION

YES	1	
NO	83	
MAYBE	1	
TYPE:	SHEEPS MAINT.	1

CROWN

0-2	6
2-4	20
4-6	35
6-8	40
8-10	24
10-12	17
12<	2

WHY
SPECF'D

STONE			GRAVEL	
A			A	
HISTORY	5		HISTORY	0
FIT NEEDS	3		FIT NEEDS	0
LOW FINES	3		LOW FINES	0
PROD.	12		PROD.	0
GRAD.	4		GRAD.	0
COST	5		COST	0
TEXTURE	4		TEXTURE	0
DURABILITY	9		DURABILITY	0
B			B	
HISTORY	4		HISTORY	1
FIT NEEDS	0		FIT NEEDS	2
LOW FINES	0		LOW FINES	3
PROD.	1		PROD.	8
GRAD.	0		GRAD.	0
COST	0		COST	3
TEXTURE	0		TEXTURE	2
DURABILITY	0		DURABILITY	1
C			C	
HISTORY	0		HISTORY	1
FIT NEEDS	0		FIT NEEDS	2
LOW FINES	0		LOW FINES	1
PROD.	0		PROD.	8
GRAD.	0		GRAD.	0
COST	0		COST	1
TEXTURE	0		TEXTURE	0
DURABILITY	0		DURABILITY	0
D				
HISTORY	1			
FIT NEEDS	1			
LOW FINES	6			
PROD.	3			
GRAD.	0			
COST	3			
TEXTURE	1			
DURABILITY	1			

ADD. SPECS

1 1 1/4 CRUSHER RUN LIMESTONE
2 LOWER #200
3 GRAVEL MODIFIED #200 0-7%
4
5 ABRASION <50, 15-30%PASSING #8
6 LIMIT THE % PASSING #200,8%
7 0-30% PASSING #4, 0-20% PASSING #8
8 % WEAR <40%, FREEZE THAW <15%
9 ABRASION <45% LOSS, FREEZE THAW <15% LOSS
10 MAX. % MUD BALLS < 4%
11 MUD BALLS <4%, ABRASION<45%, FREEZE THAW <15%
12 LARGER GRADATION "D" TO IMPROVE LIFE OF STONE
13 % PASSING #8 <30%
14 MAY MOVE THE #4 & #8 PERCENTAGES
15 3/4" MINUS AS CRUSHED FROM CLAY CO. PITS
16 20-30% PASSING #8 SIEVE
17 AASHTO T96 <45%, MUDBALLS <4%
18 DOT A MODIFIED TO 1" 100%, #4 75%, #8 20-33%
19 ALLOW MORE TO PASS #4,#8 SIEVES
20 ROCK HAS A TOP SIZE 1 1/8", SCREEN OUT <#8
21 MIN 7% CRUSHED PARTICLES
22 MUDBALLS <4%
23 1" TOPSIZE OR 11/2" CLEAN, LOW FINES
24 USE AS IS FROM COUNTY PITS
25 TO MEET COUNTY'S APPROVAL
26 MUDBALLS <4%
27 SPECS VARY WITHSTONE AVALABLE IN PITS
28 GRADATION MAY BE VARIED DO TO FREEZE THAW
29 MAX. SIZE IS 1 1/4"
30 #8 18-28%
31 VISABLE INSPECTION
32 15% PASSING #8
33 MUDBALLS <4%, FREEZE-THAW <15%, GRADATION #24
34 1 1/4 TOPSIZE AND REDUCE WHAT PASSES #6
35 STONE "A" MODIFIED TO GRADATION #25
36 1" MAX., MUDBALLS <4%, #8 20-40%
36 ABRASION <45%, FREEZE-THAW <15%
37 1" MODIFIED
38 CLASS A WITH, 1 1/4" 97-100%, #8 10-25%
39 LIMIT AMOUNT PASSING #200
40 CONTROL THE AMOUNT OF SHALE IN MATERIAL

MAINTENANCE PRACTICE'S

GRADING FACTORS		GRADING PERIOD	
WEATHER	75	0-7	26
TRAFFIC	68	7-14	52
P.R.	2	14-21	20
MATERIALS	16	21<	11
CONDITION	15		
MANPOWER	4		
TREATED	1		

SOIL
SUBGRADE

CLAY	50	DESIGN
SAND	5	FACTOR
SILT	24	
BEDROCK	3	
GUMBO	4	
SIL. CLAY	11	
SA. CLAY	6	
PEAT	1	
SHALE	1	

YES 34
NO 49

WHY

1 ONLY IN AREAS OF BLACK SOIL
2 TILLS ARE NOT BEST SOILS TO USE
3 GUMBO AREAS NEARLY IMPOSSABLE TO KEEP SURFACED
4 CERTAIN AREAA DO REQUIRE MORE YARDAGE AND COMPACTION
5 MORE FREQUENT GRADING DO TO POOR DRAINAGE AND LOWER
STABILITIE
6 LIMESTONE BONDS DIFFERENTLY WITH DIFFERENT SOILS
7 SUBGRADE MOISTURE AND SURFACE STABILITY DUE TO DITCH
DEPTH
8 FROST BOILS
9 DO NOT HAVE A STABLE SOIL WHEN WET
10 SOILS ALLOW THE ROCK TO PENATRATE
11 LARGER LOADS CAUSE PUMPING OF THE SOIL
12 VERY POOR SUBGRADE SOIL
13 MOVES WHEN WET
14 POORLY DRAINING SOILS
15 SOIL PUMPING
16 THICK TOP SOIL MAKES FOR POOR ROAD GRADES
17 BETTER IN SANDY CLAY, WORST IN THE TILL
18 UNSTABLE SUBGRADE
19 CLAY SUBGRADE NEEDS LESS REPLENISHMENT THAN LOAM
20 PEAT AREAS ALLOW SUBGRADE INTRUSION
21 SUBGRADE DRAINAGE MUUST BE KEPT ADEQUATE
22 SUBGRADE CONDITOINS CHANGE RAPIDLY
23 DIFFERT SOILS SUPPORT THE SURFACING MATERIAL BETTER
24 LOESS HILLS PRESENT EROSION & MATERIAL LOSS PROBLEMS
25 TRAFFIC & MAINTENERS HABITS
26 HIGH ERODABILITY AND DIFFICULT TO COMPACT
27 NO STABILITY OR DRAINAGE
28 SOILS THAT HOLD MOISTURE PROVIDE LESS STABILITY
29 WET SLAY MAKES POOR SUBBASE
30 SANDY AREAS MAY BE GULLING

DUST PROGRAM					
		TYPE		MILES	
YES	43	CaCl	34	0-10	21
NO	40	WATER	0	10-20	6
		OIL	4	20-30	2
		LIG'N SULF	11	30-40	1
		SEAL COAT	3	40-50	1
				50<	4

PROBLEM SEVERITY	WASHBOARD	POTHOLING	RUTTING	DUST	SUBGRADE INTRUSION	MATERIAL LOSS	OTHERS
1	2	1	3	5	6	4	
2	6	5	4	1	2	3	
3	4	5	2	6	1	3	
4	3	1	6	2	5	4	
5	6	5	3	4	2	1	
6	2	4	3	4	4	1	
7	4	2	3	6	5	1	
8	3	4	4	2	4	1	
9	1	3	4	2	6	5	
10	2	1	4	3	6	5	
11	3	2	1	6	4	5	
12	2	1	3	5	6	4	
13	2	2	2	3	4	1	
14	2	1	3	4	6	5	
15	2	1	4	6	3	5	
16	1	2	2	5	6	4	
17	7	4	3	6	5	1	
18	4	5	6	3	1	2	
19	7	4	5	2	6	3	
20	1	2	3	6	5	4	
21	3	1	5	6	2	4	
22	1	4	3	5	6	2	
23	4	2	3	6	5	1	
24	5	3	6	2	4	1	
25	2	3	4	5	6	1	
26	5	5	4	5	3	2	
27	3	4	5	2	6	1	
28	1	4	5	3	6	2	
29	2	4	1	6	3	5	
30	2	4	5	3	6	1	
31	5	4	1	2	2	3	
32	2	1	3	5	6	4	
33	1	2	4	5	6	3	
34	3	4	2	5	2	1	
35	3	4	1	6	2	5	
36	1	1	2	2	2	2	
37	5	4	6	3	2	1	
38	4	2	3	5	6	1	
39	2	4	5	1	6	3	
40	2	3	5	6	4	1	
41	3	2	4	1	6	5	
42	1	4	3	6	5	2	
43	3	5	4	6	2	1	
44	2	3	1	4	6	5	
45	1	4	3	5	2	6	
46	3	2	4	1	6	5	
47	5	3	4	2	6	1	
48	1	2	3	6	4	5	

FROST BOILS
SHOULDER BERMS
TRAFFIC DEGRAD.
KEEPING THE CROWN
DOUBLE DITCHES
POOR AGGREGATE
SECONDARY DITCHES

49	1	2	5	6	3	4
50	2	1	3	6	4	5
51	3	2	6	5	1	4
52	1	3	4	6	5	2
53	4	3	5	1	6	2
54	1	5	6	3	4	2
55	4	5	6	3	2	1
56	1	4	6	5	2	3
57	1	2	1	6	5	4
58	2	4	5	3	6	1
59	2	1	5	3	6	4
60	4	1	5	2	5	3
61	6	4	5	2	3	1
62	2	1	3	6	4	5
63	1	2	5	3	6	4
64	2	1	3	5	6	4
65	5	4	3	6	1	2
66	2	5	3	4	6	1
67	4	2	5	6	3	1
68	3	4	2	6	1	5
69	2	1	3	5	6	4
70	2	1	6	3	5	4
71	1	3	5	2	6	4
72	2	5	6	1	4	3
73	3	2	1	5	6	4
74	1	6	5	2	4	3
75	1	6	3	2	5	4
76	5	1	6	2	3	4
77	4	3	5	1	6	2
78	1	4	5	2	6	3
79	3	1	6	2	5	4
80	5	4	3	6	2	1
81	3	2	1	6	5	4
82	6	3	2	5	4	1
83	1	2	4	3	6	5
84	1	3	2	4	6	5
85	1	2	3	5	6	4
86	4	2	3	5	6	1
	236	250	322	343	379	254

APPENDIX C

SURFACING MATERIAL GRADATION TESTS

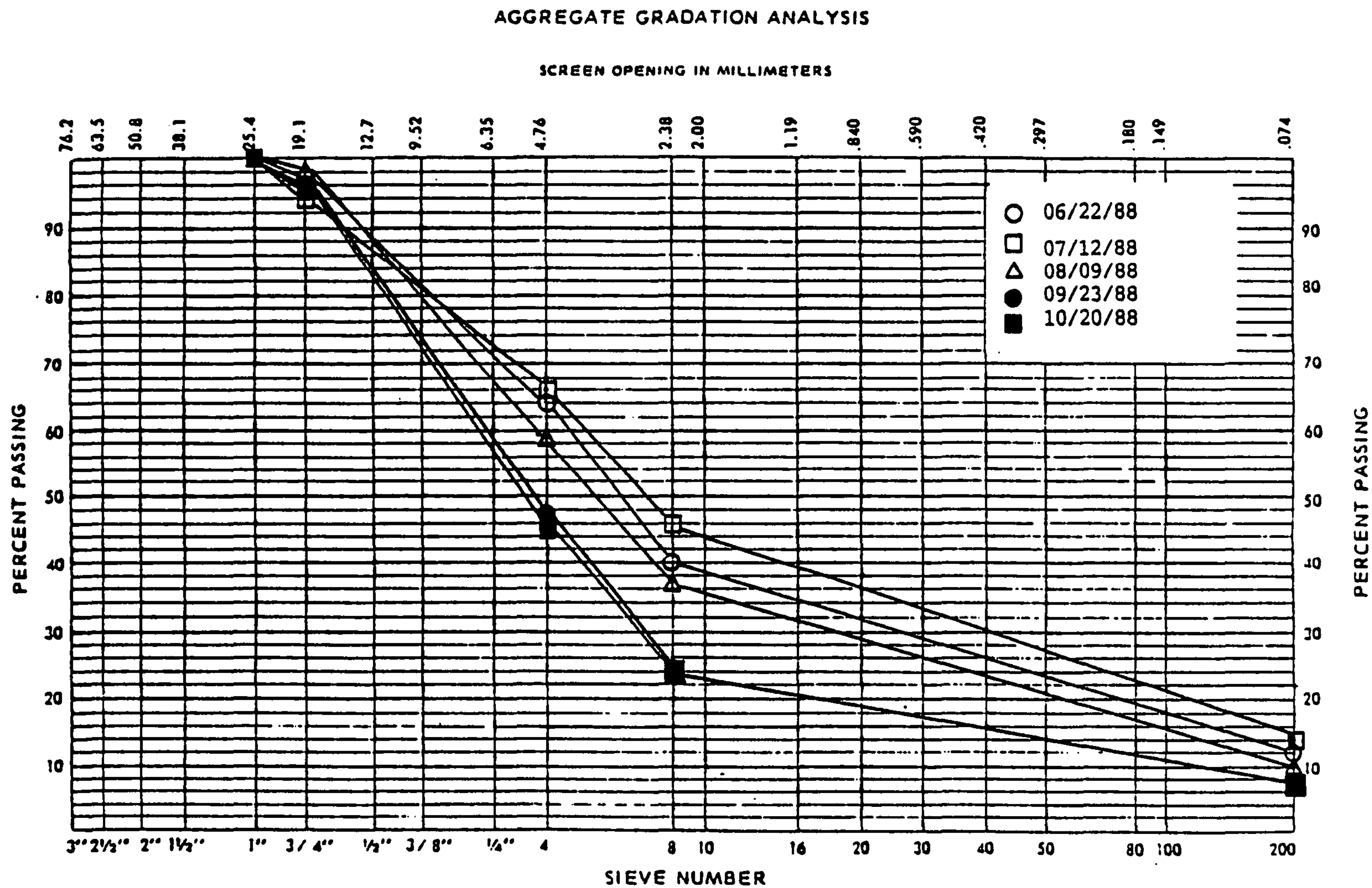


Figure 1. Surfacing Gradation Results for Section 1

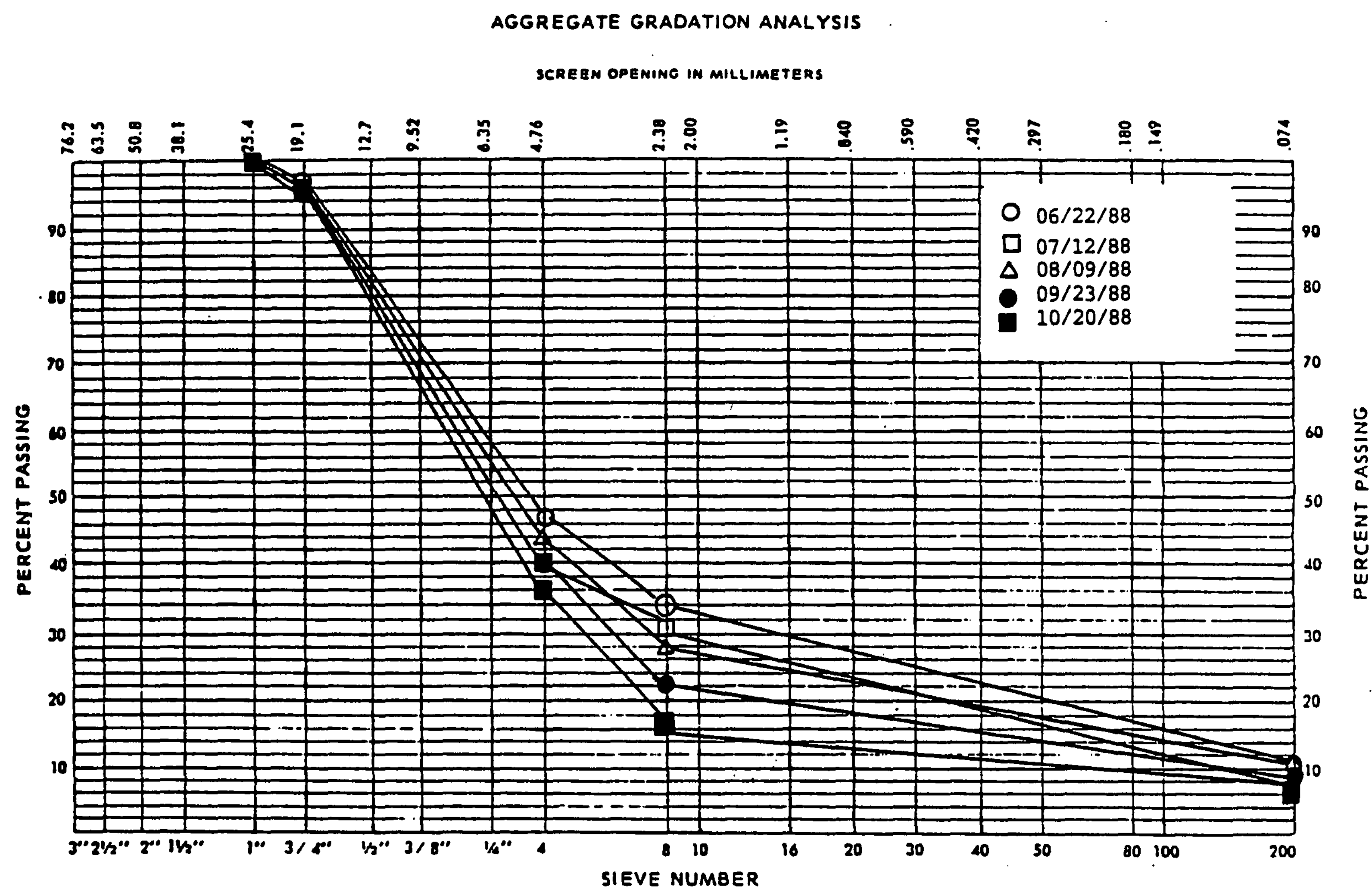


Figure 2. Surfacing Gradation Results for Section 2

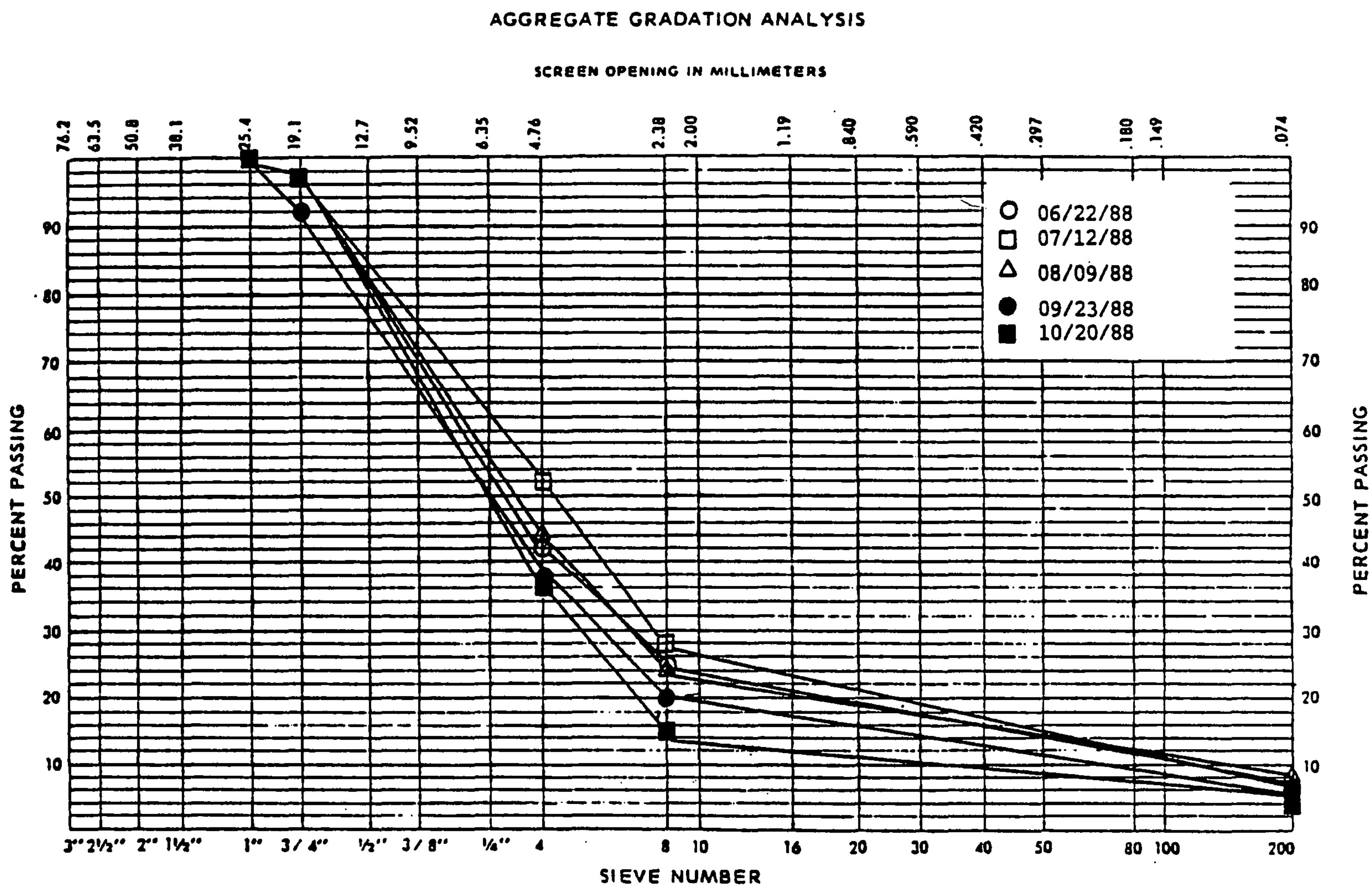


Figure 3. Surfacing Gradation Results for Section 3

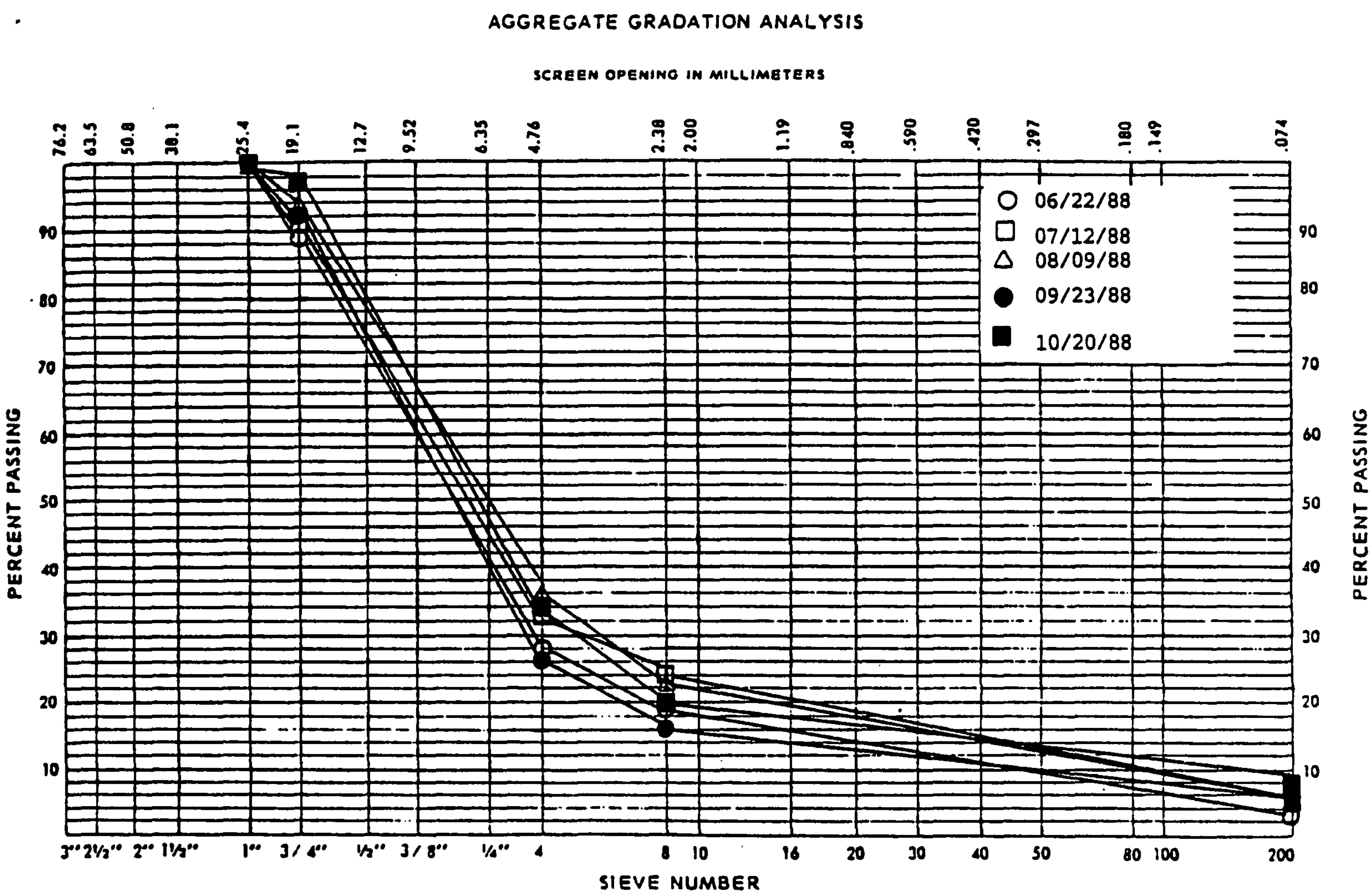


Figure 4. Surfacing Gradation Results for Section 4

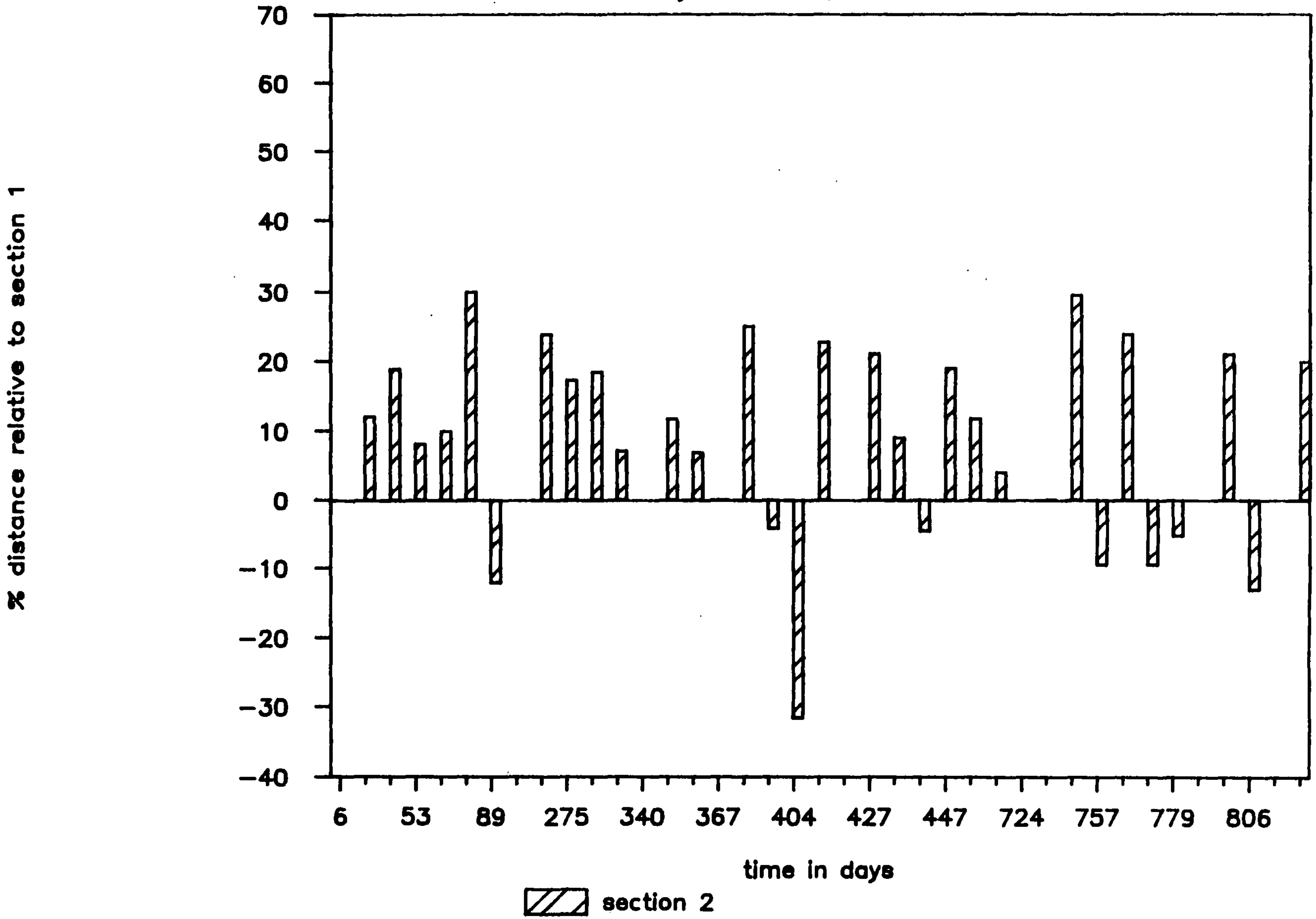
APPENDIX D

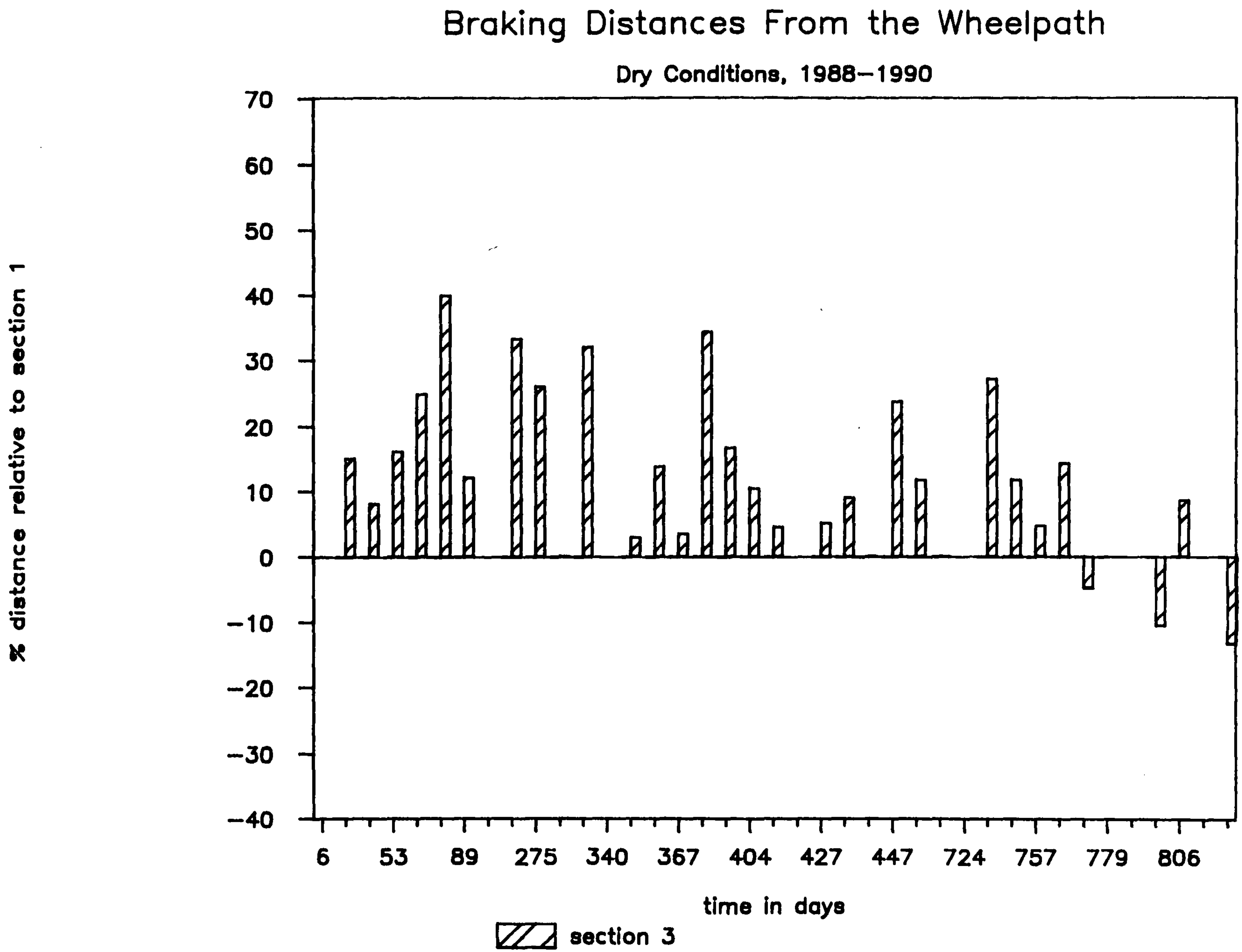
BRAKING TEST DATA

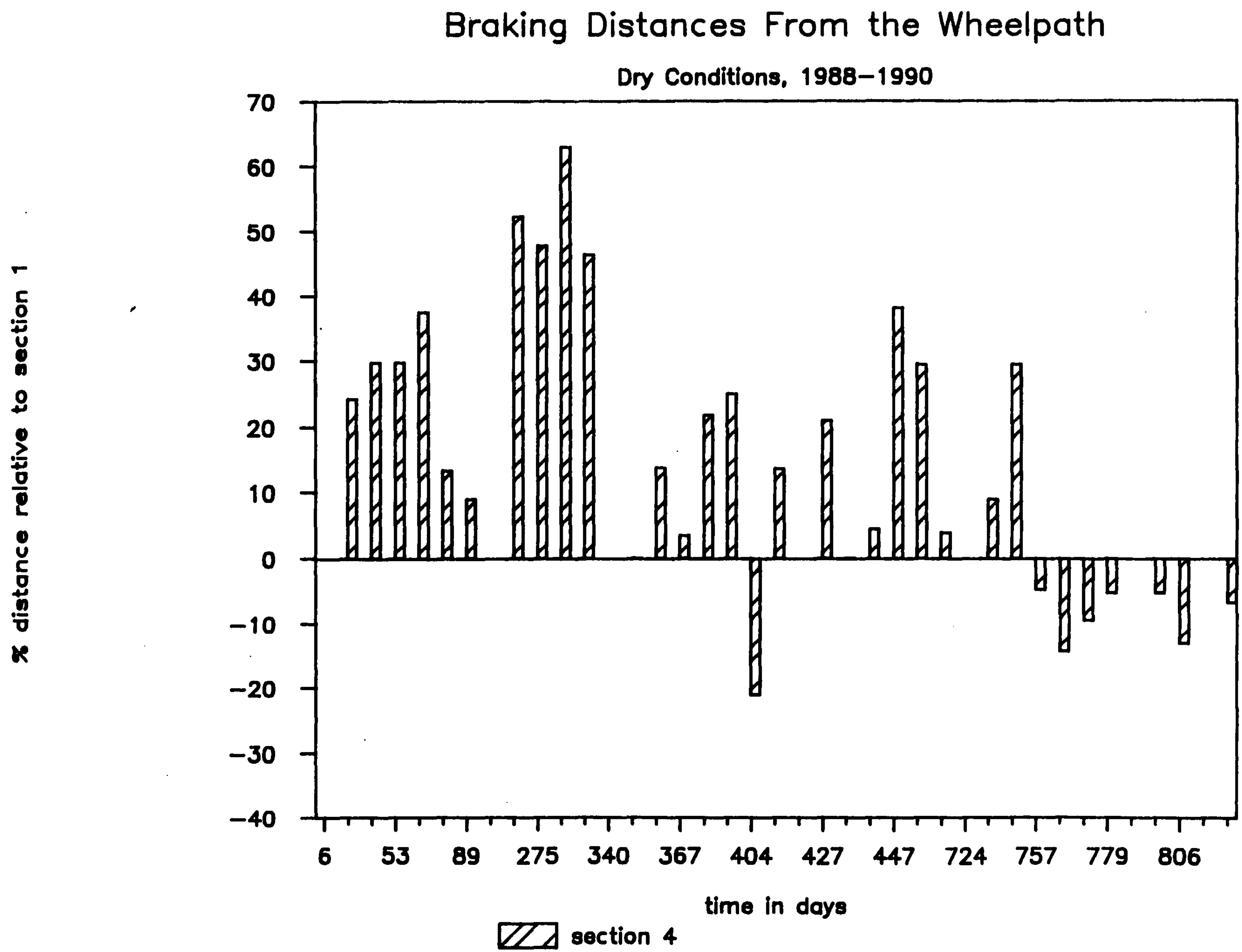
APPENDIX D

Braking Distances From the Wheelpath

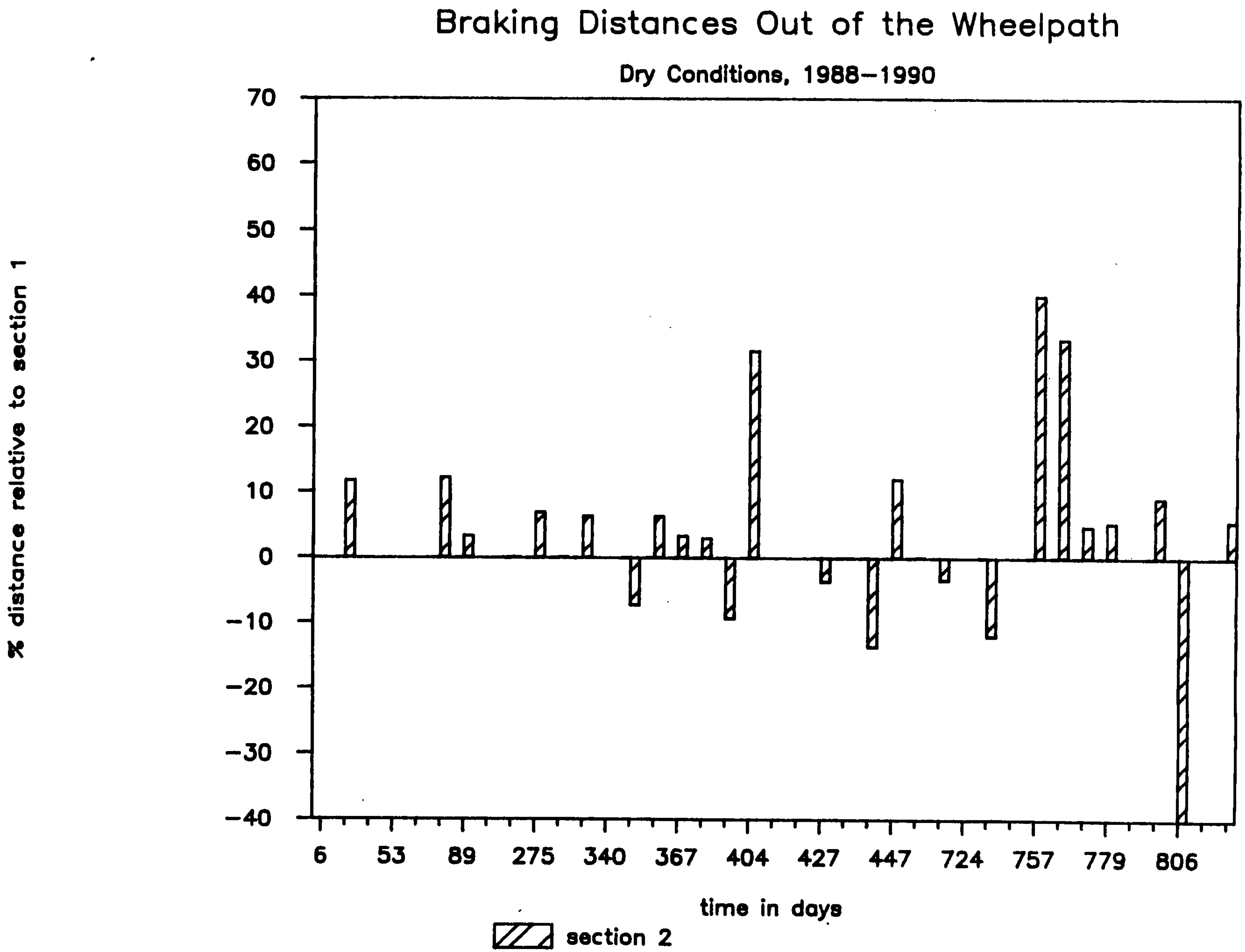
Dry Conditions, 1988–1990



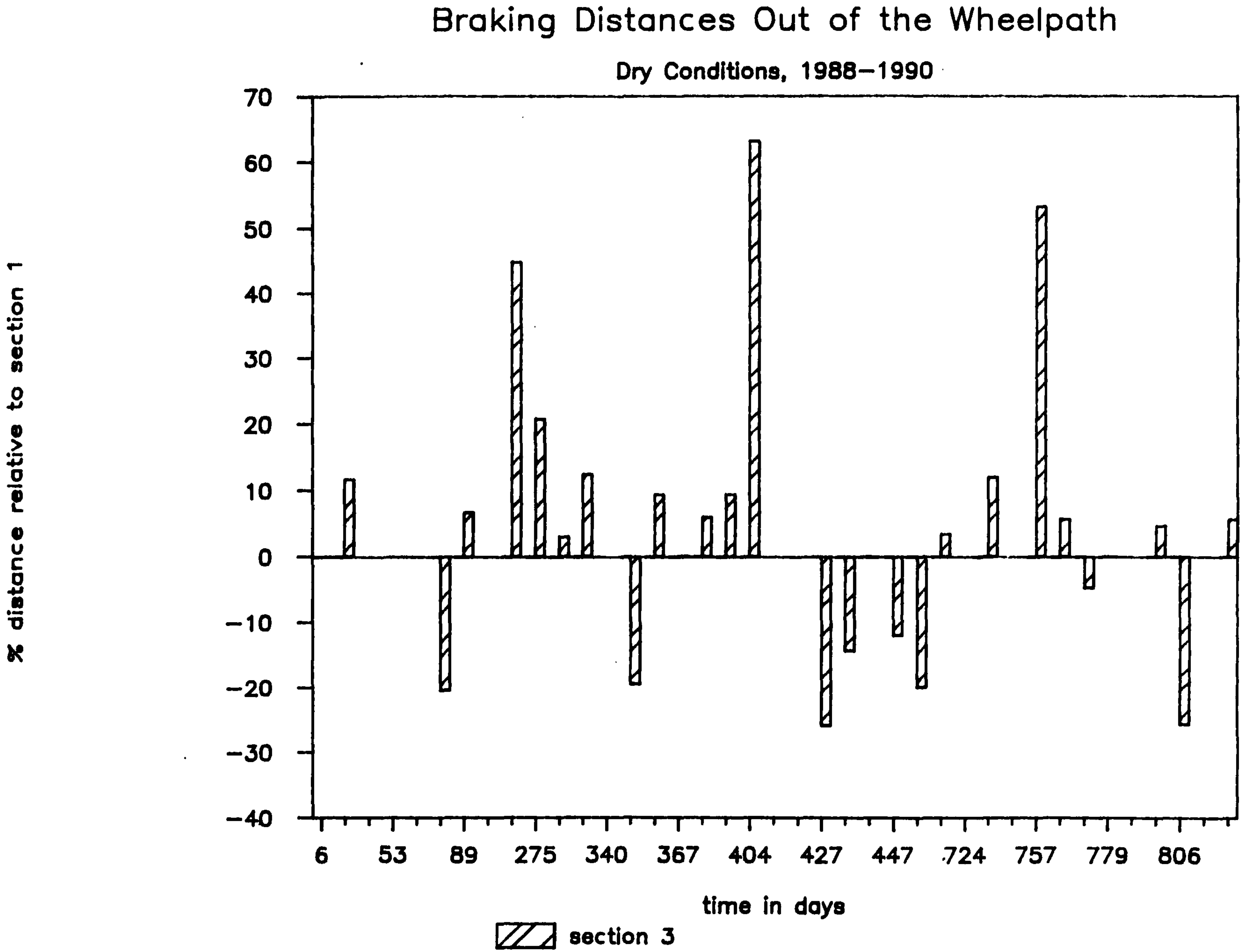

Braking Distances From the Wheelpath
Dry Conditions, 1988–1990
% distance relative to section 1
70
60
50
40
30
20
10
0
–10
–20
–30
–40
6
53
89
275
340
367
404
427
447
724
757
779
806
time in days
section 3



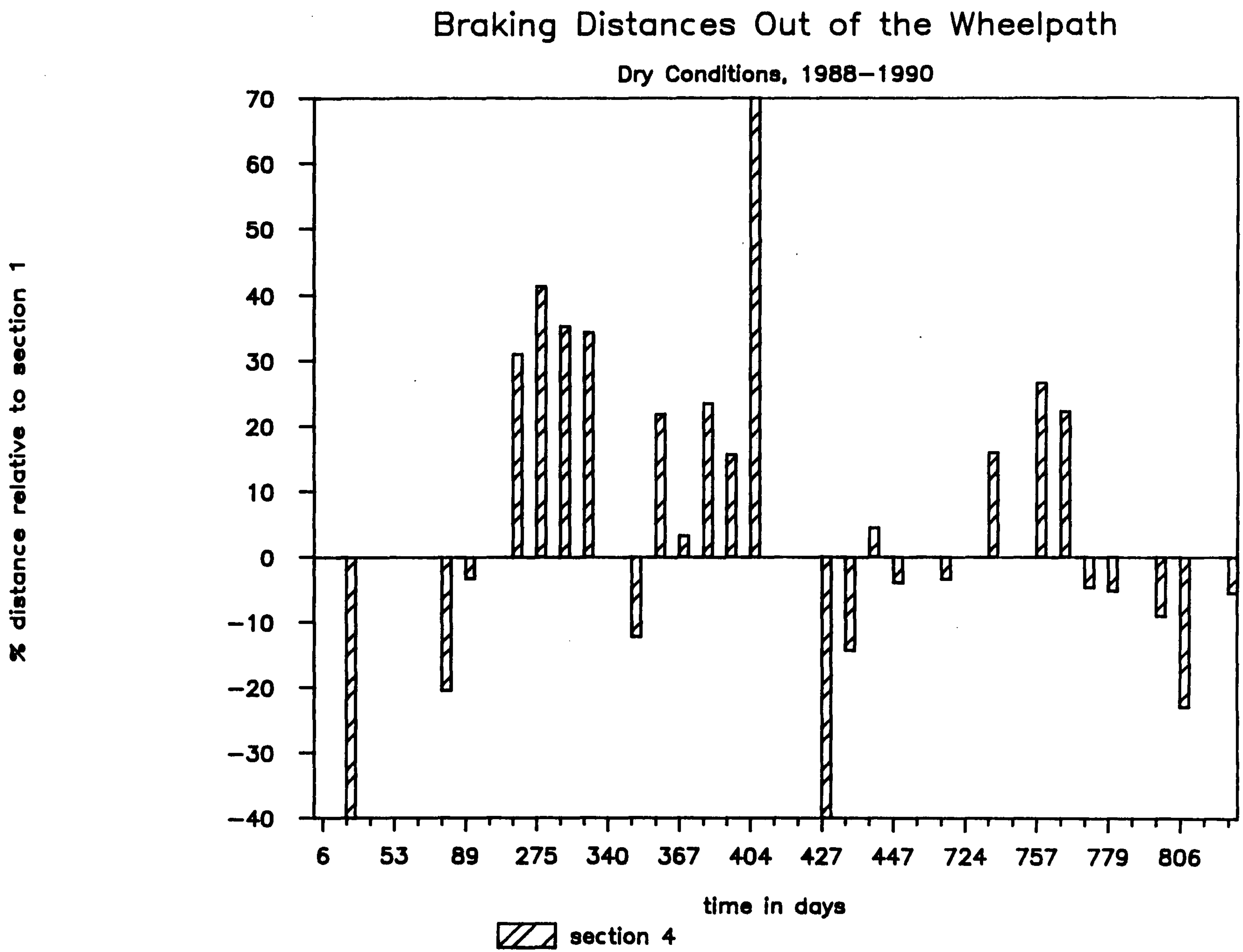
Braking Distances From the Wheelpath
Dry Conditions, 1988–1990
% distance relative to section 1
70
60
50
40
30
20
10
0
−10
−20
−30
−40
6
53
89
275
340
367
404
427
447
724
757
779
806
time in days
section 4



Braking Distances Out of the Wheelpath
Dry Conditions, 1988–1990
% distance relative to section 1
70
60
50
40
30
20
10
0
–10
–20
–30
–40
6
53
89
275
340
367
404
427
447
724
757
779
806
time in days
section 2



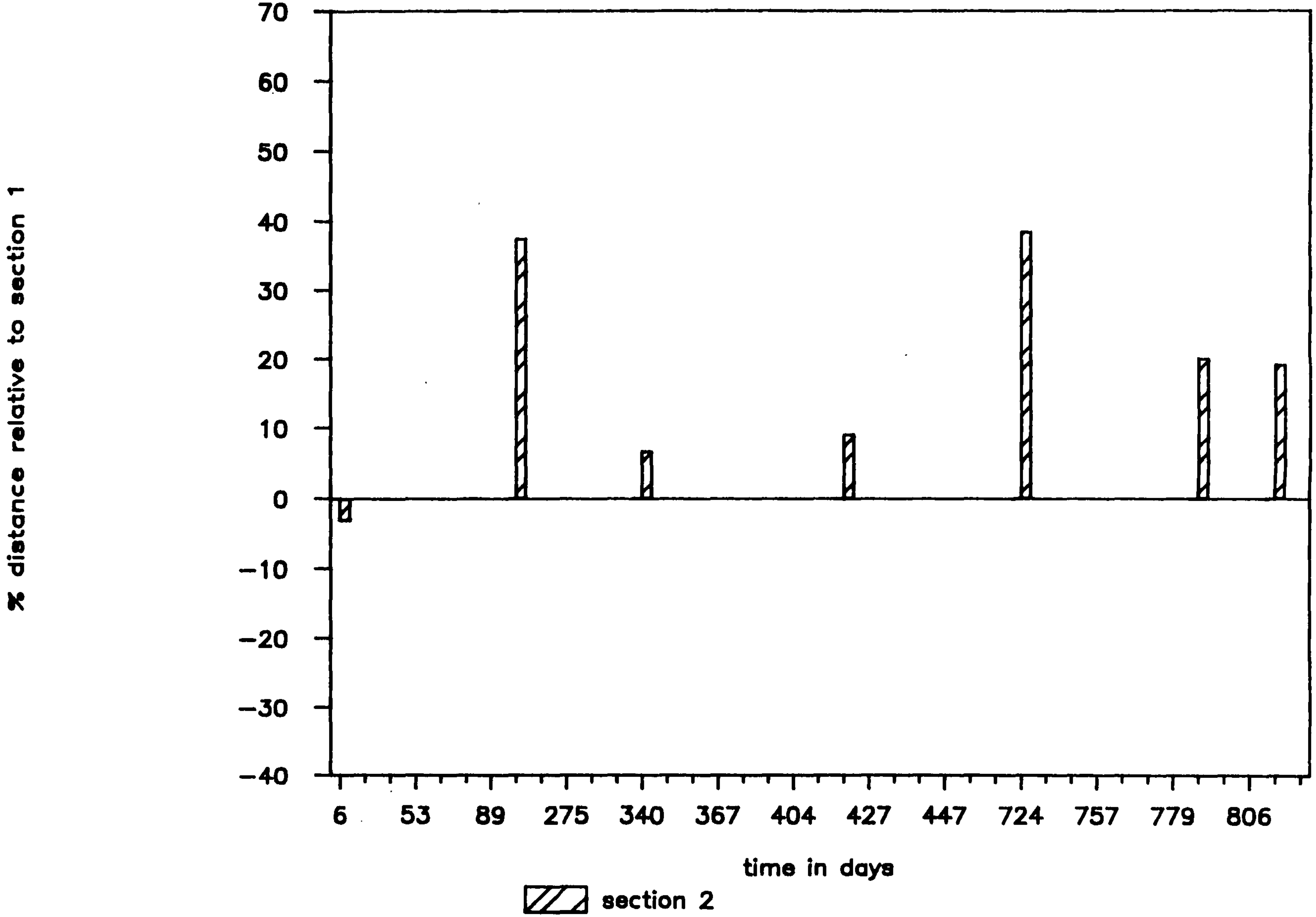
Braking Distances Out of the Wheelpath
Dry Conditions, 1988–1990
70
60
50
40
30
20
10
0
−10
−20
−30
−40
% distance relative to section 1
6
53
89
275
340
367
404
427
447
724
757
779
806
time in days
section 3



Braking Distances Out of the Wheelpath
Dry Conditions, 1988–1990
% distance relative to section 1
70
60
50
40
30
20
10
0
−10
−20
−30
−40
6
53
89
275
340
367
404
427
447
724
757
779
806
time in days
section 4

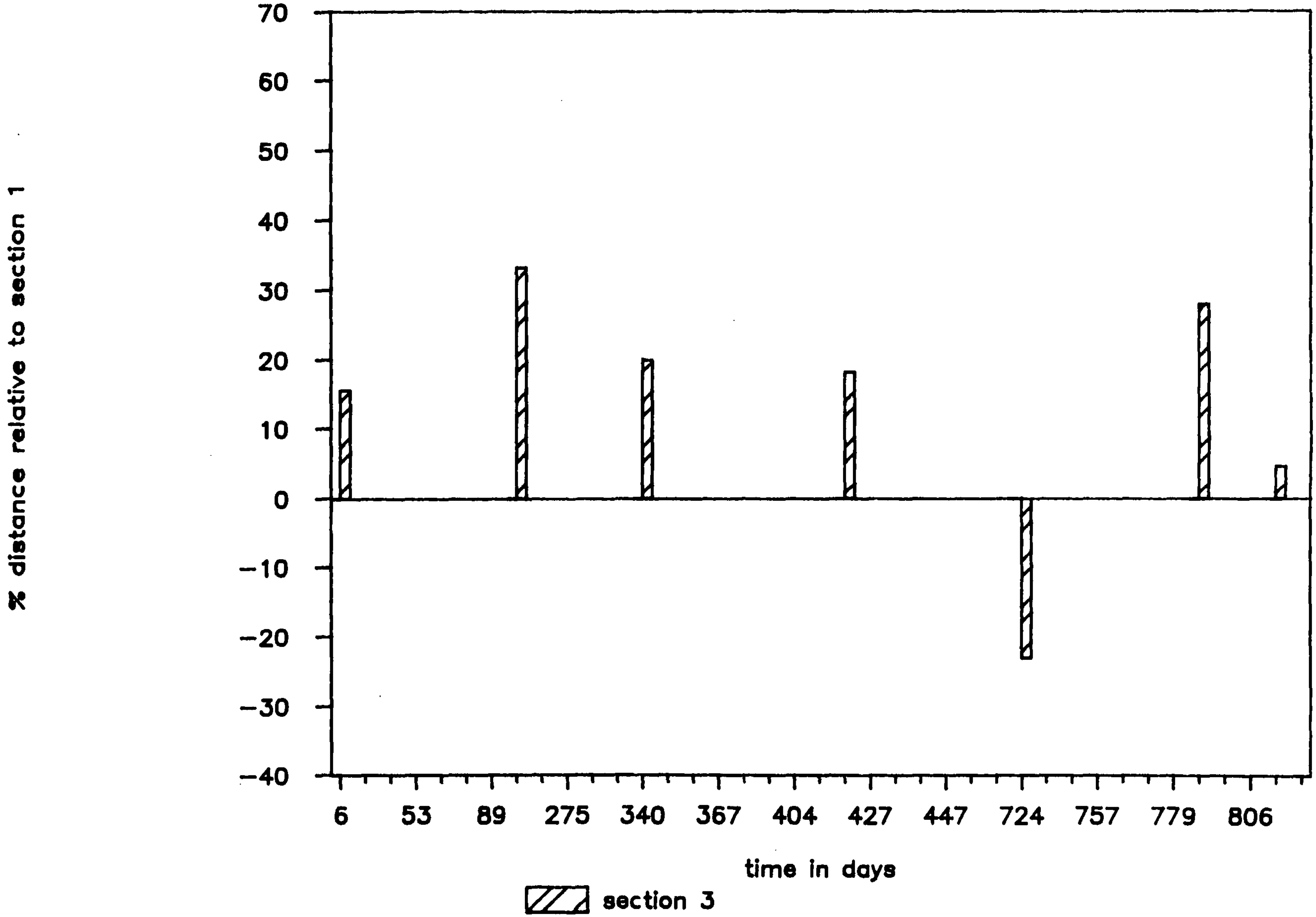
Braking Distances From the Wheelpath

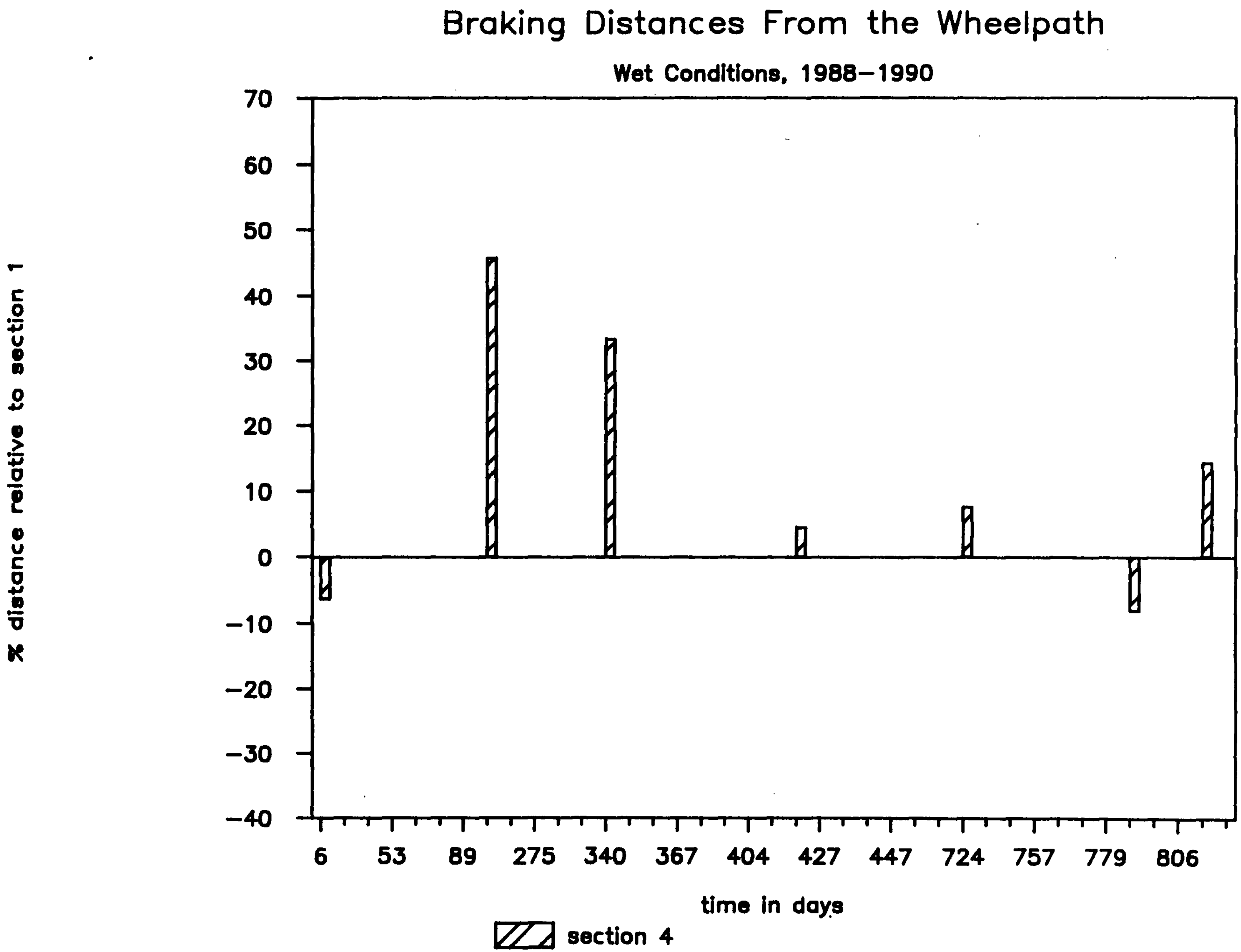
Wet Conditions, 1988–1990



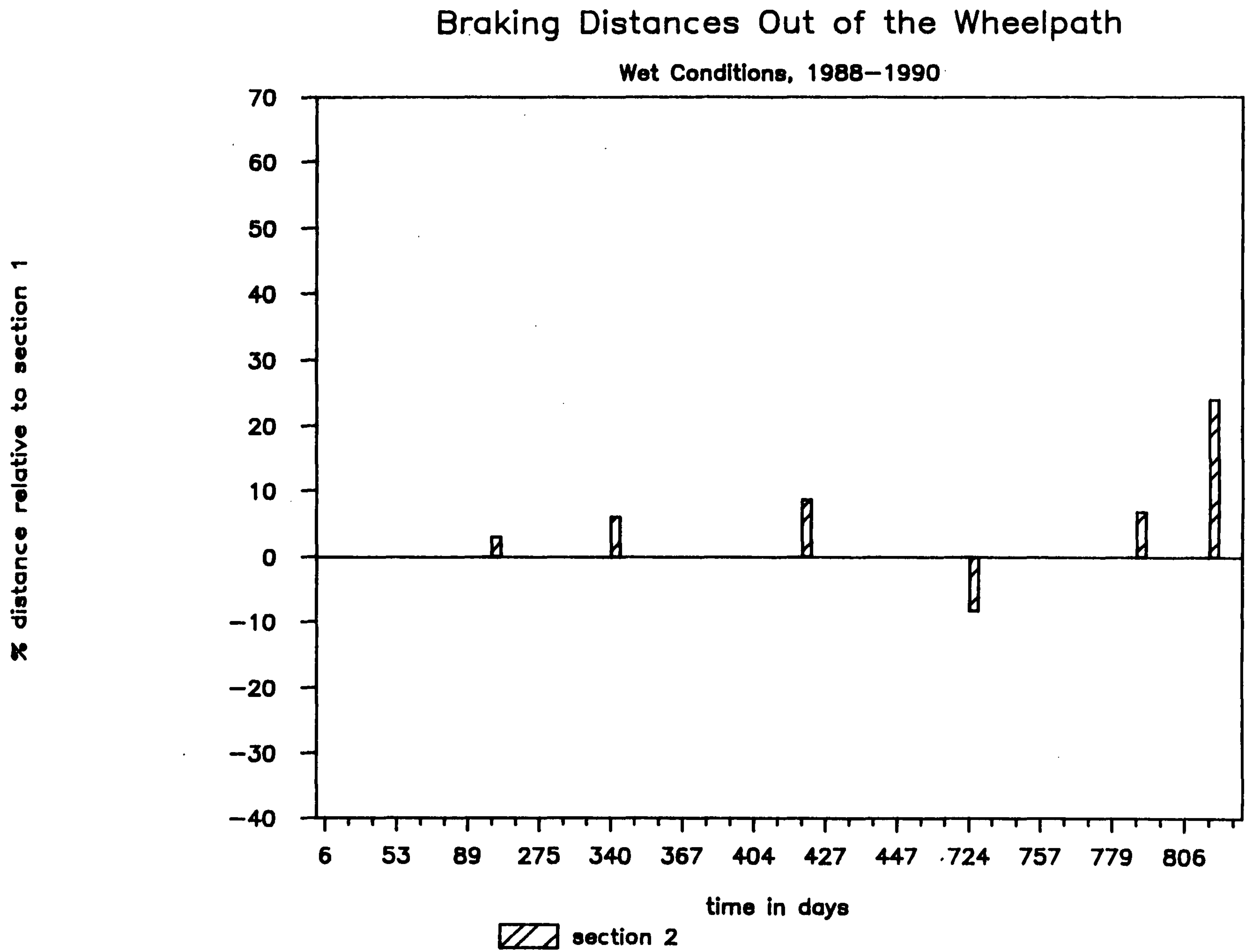
Braking Distances From the Wheelpath

Wet Conditions, 1988–1990





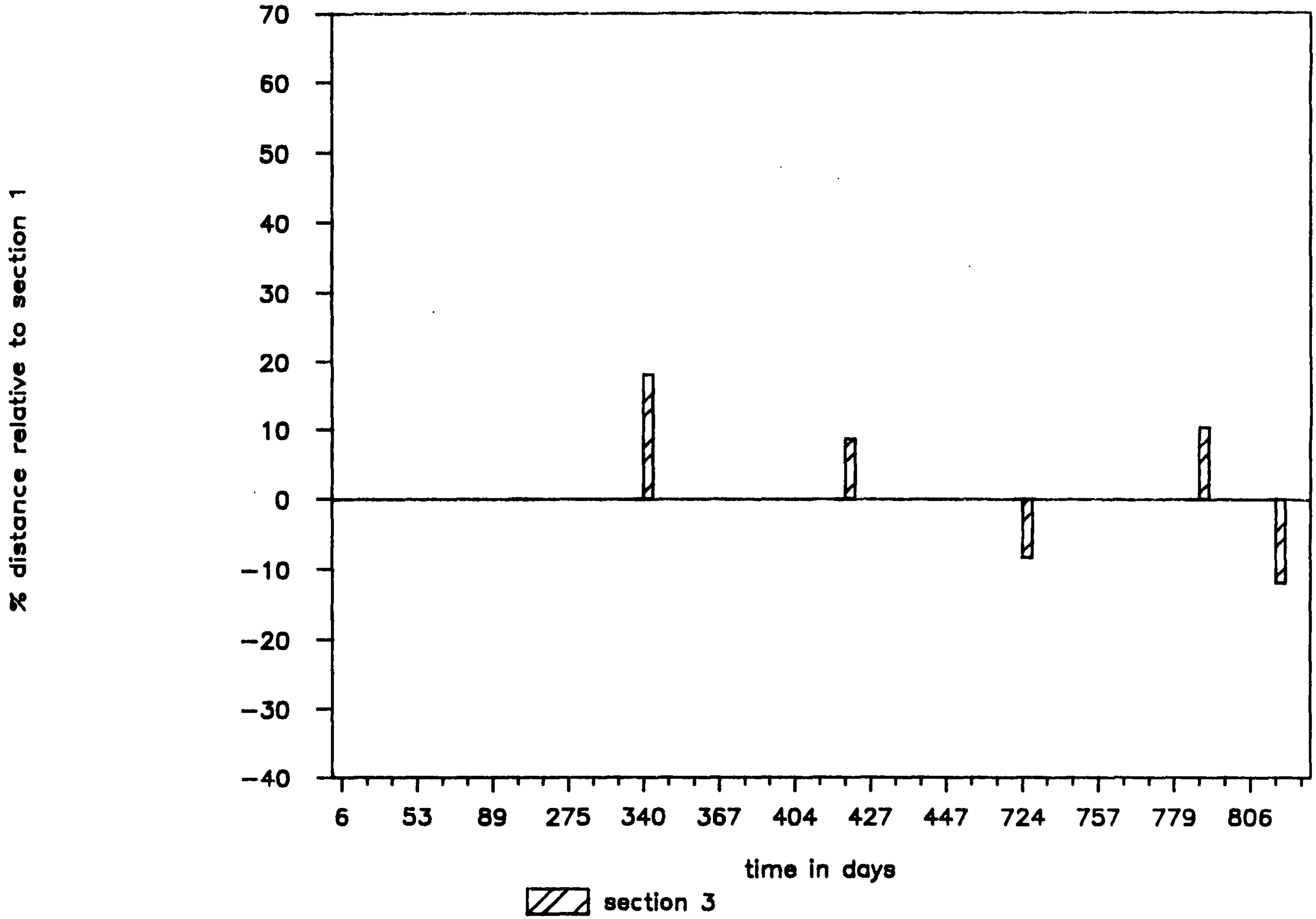
Braking Distances From the Wheelpath
Wet Conditions, 1988–1990
% distance relative to section 1
70
60
50
40
30
20
10
0
−10
−20
−30
−40
6
53
89
275
340
367
404
427
447
724
757
779
806
time in days
section 4



Braking Distances Out of the Wheelpath
Wet Conditions, 1988-1990
70
60
50
40
30
20
10
0
−10
−20
−30
−40
% distance relative to section 1
6
53
89
275
340
367
404
427
447
724
757
779
806
time in days
section 2

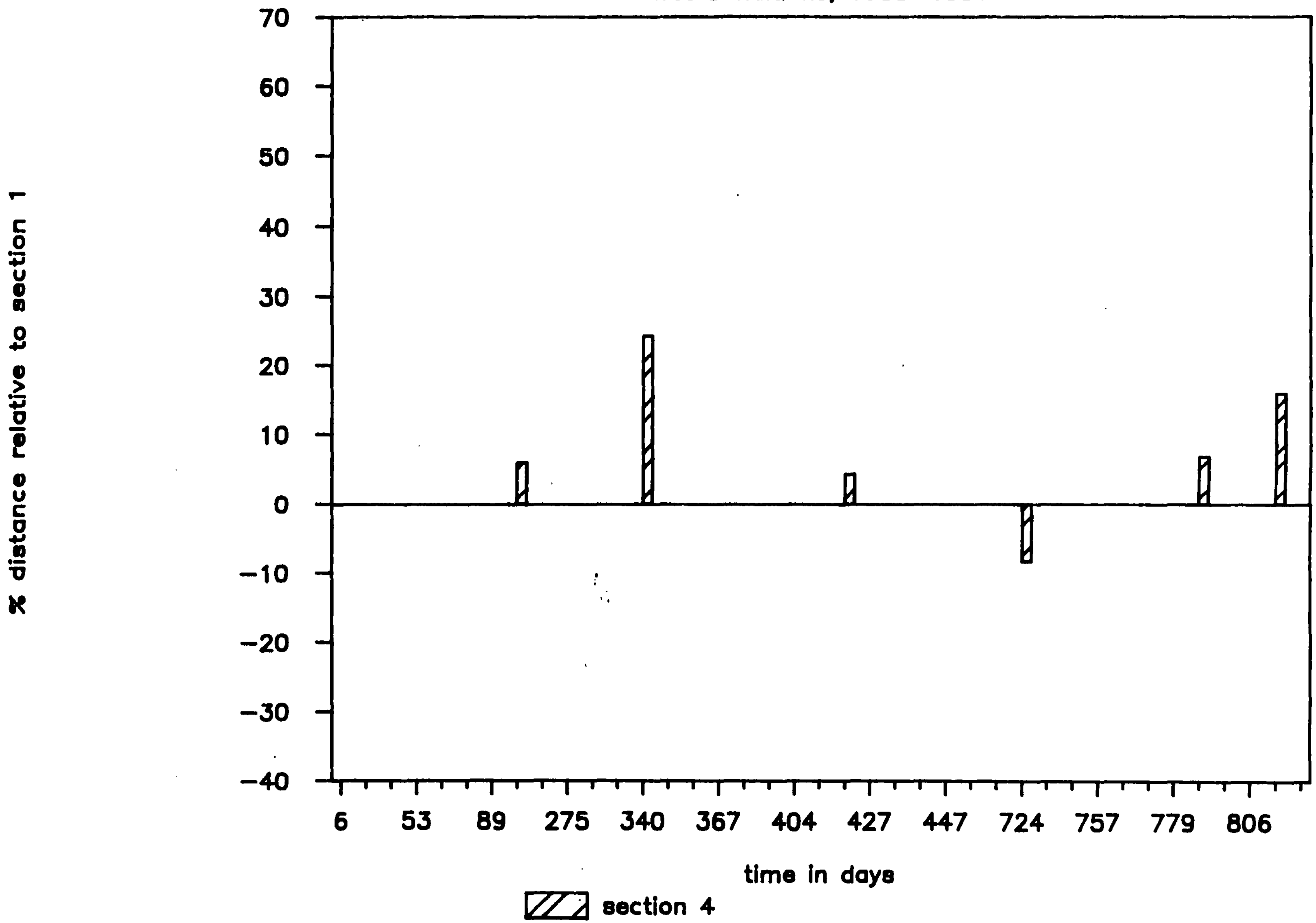
Braking Distances Out of the Wheelpath

Wet Conditions, 1988–1990



Braking Distances Out of the Wheelpath

Wet Conditions, 1988–1990



APPENDIX E

AGGREGATE THROW-OFF DATA

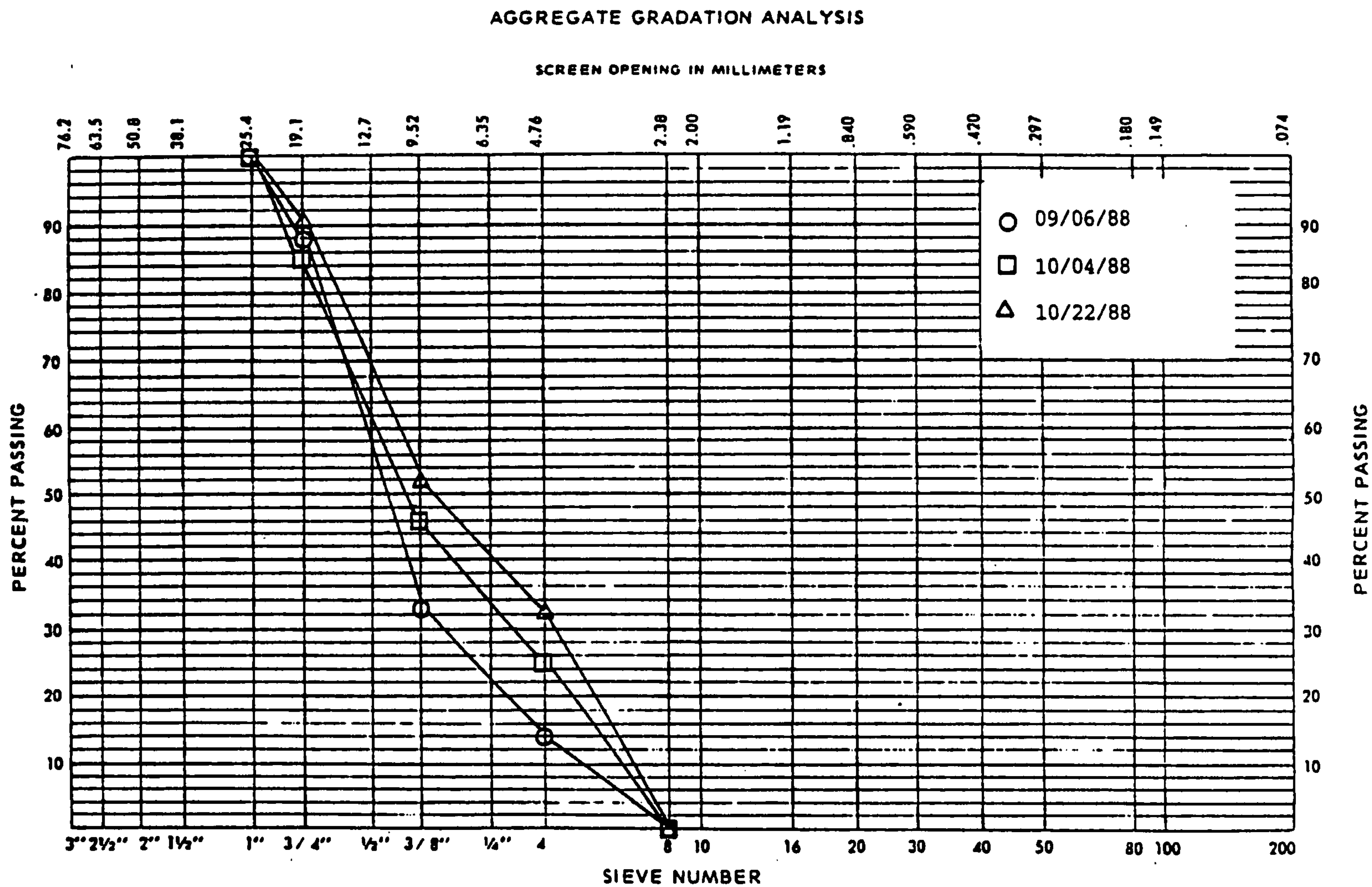


Figure 1. Throw-off material gradations for fine section 1

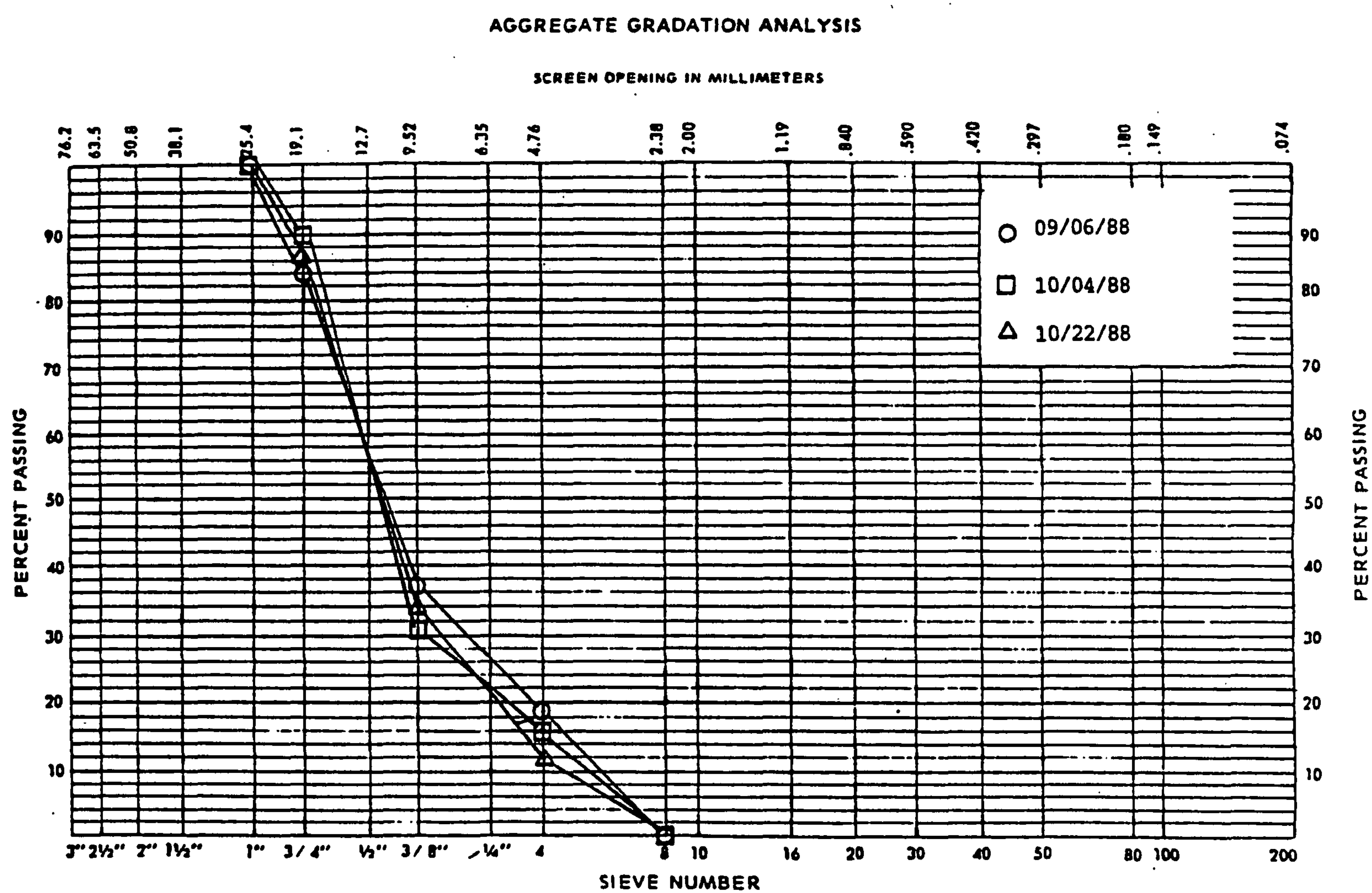


Figure 2. Throw-off material gradations for intermediate fine section 2

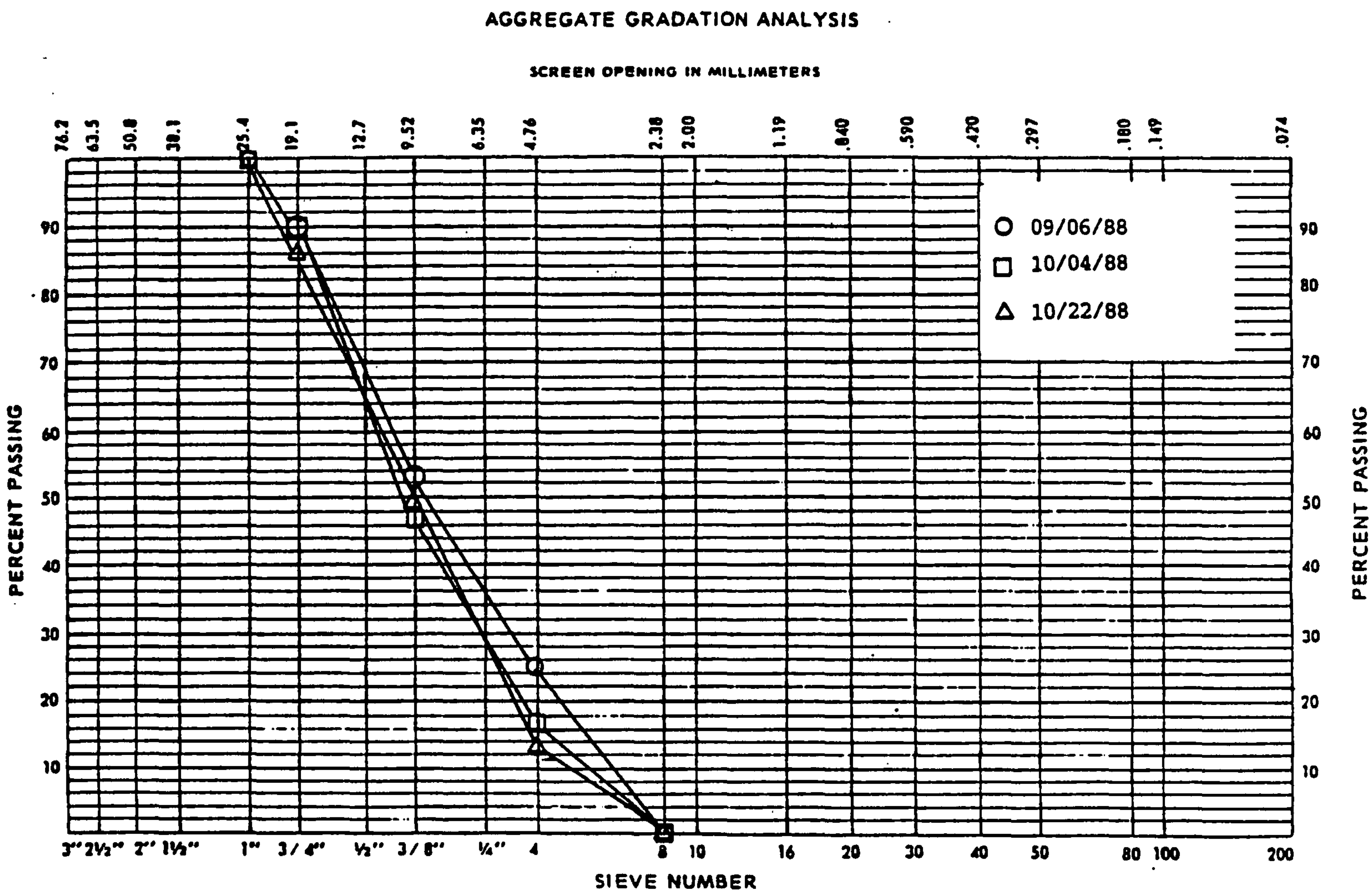


Figure 3. Throw-off material gradations for intermediate coarse section 3

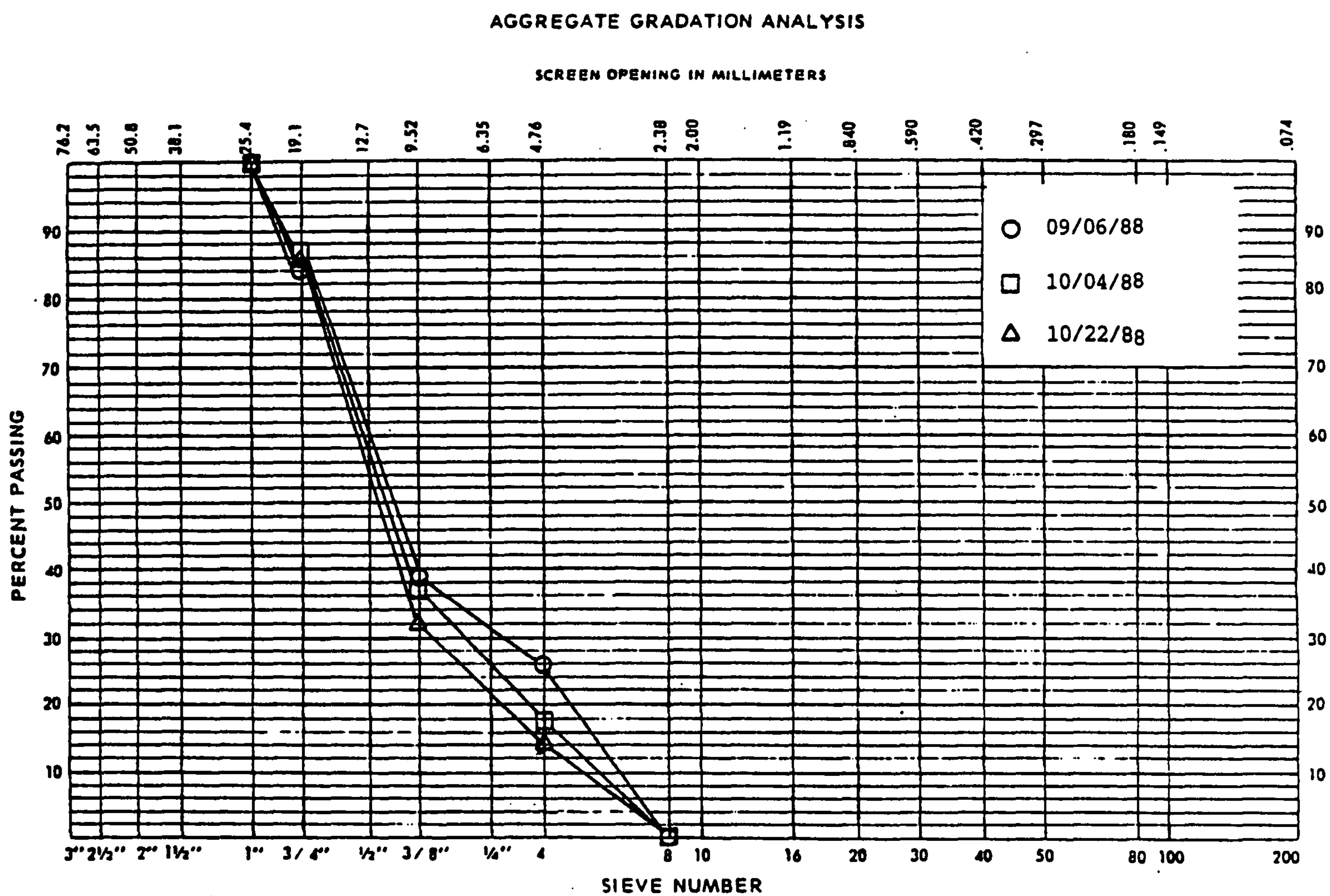
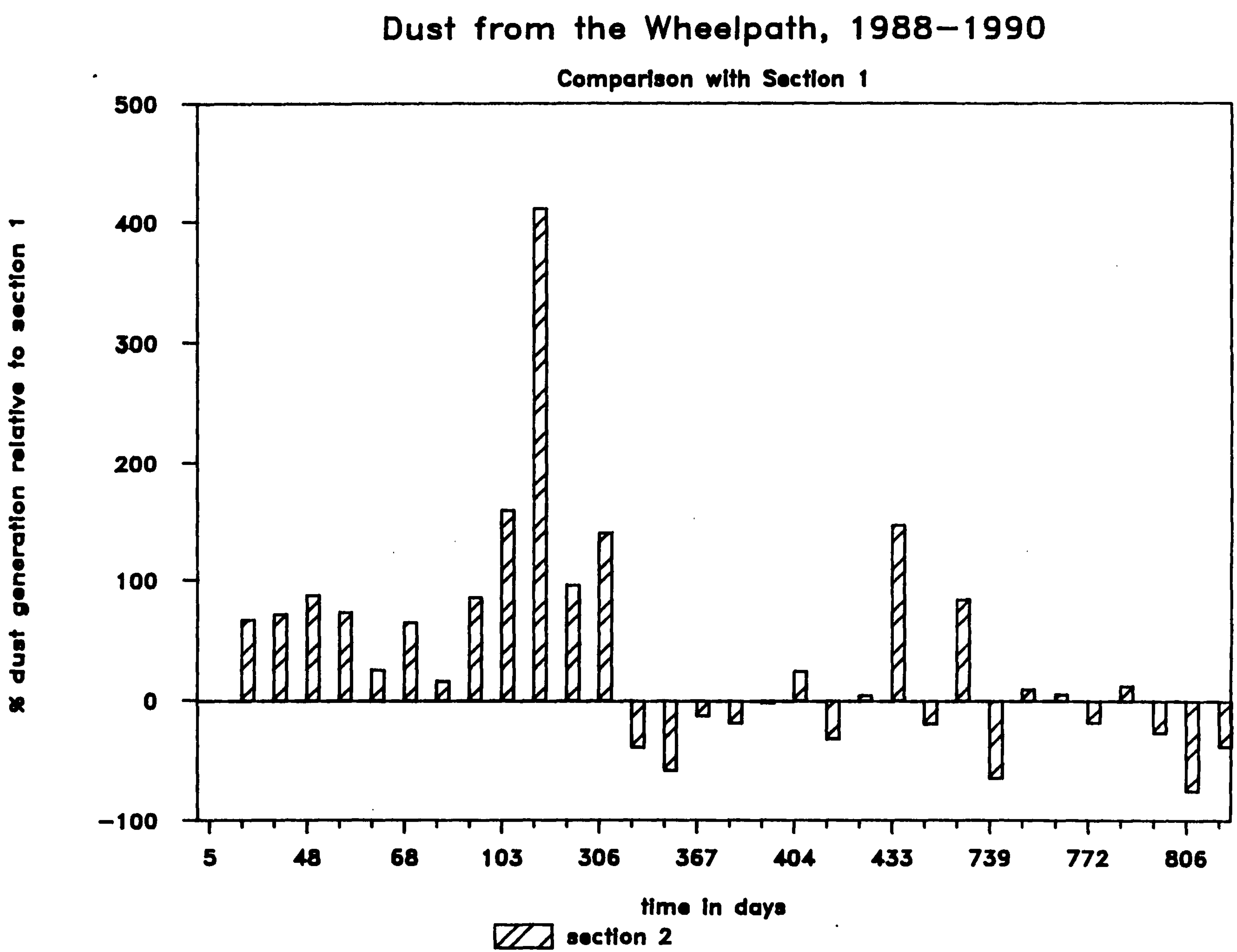
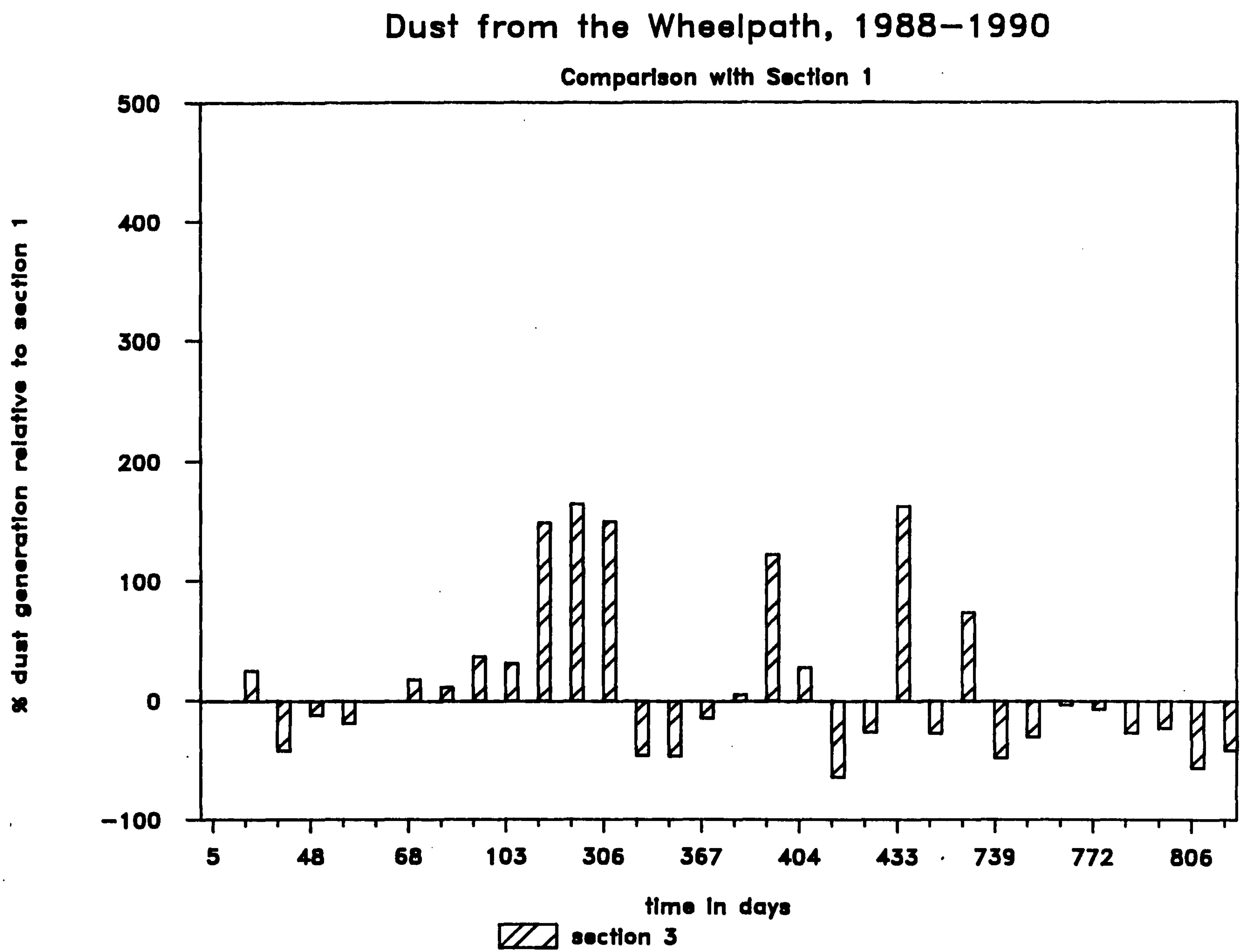


Figure 4. Throw-off material gradations for coarse section 4

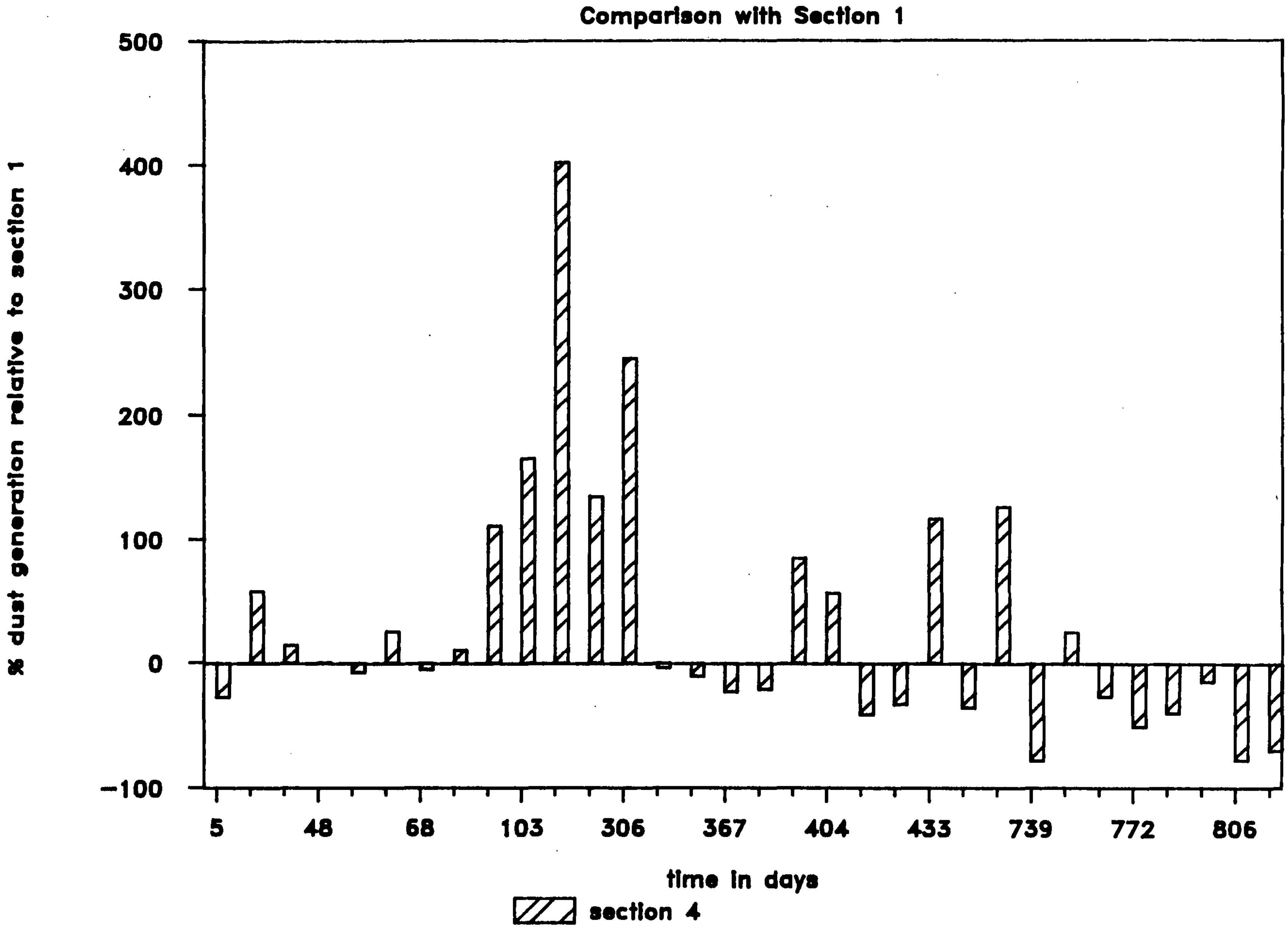
APPENDIX F

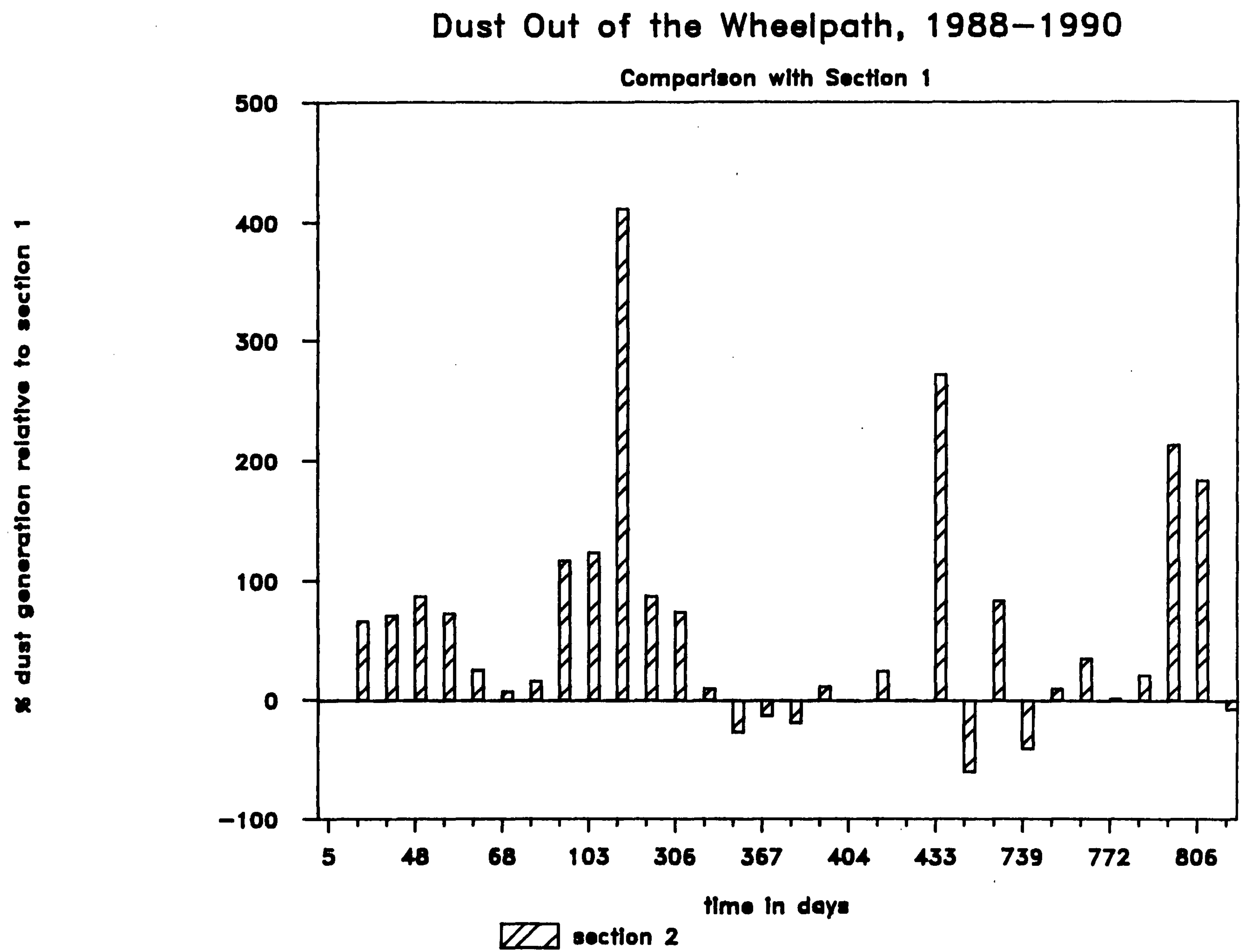
DUST GENERATION DATA

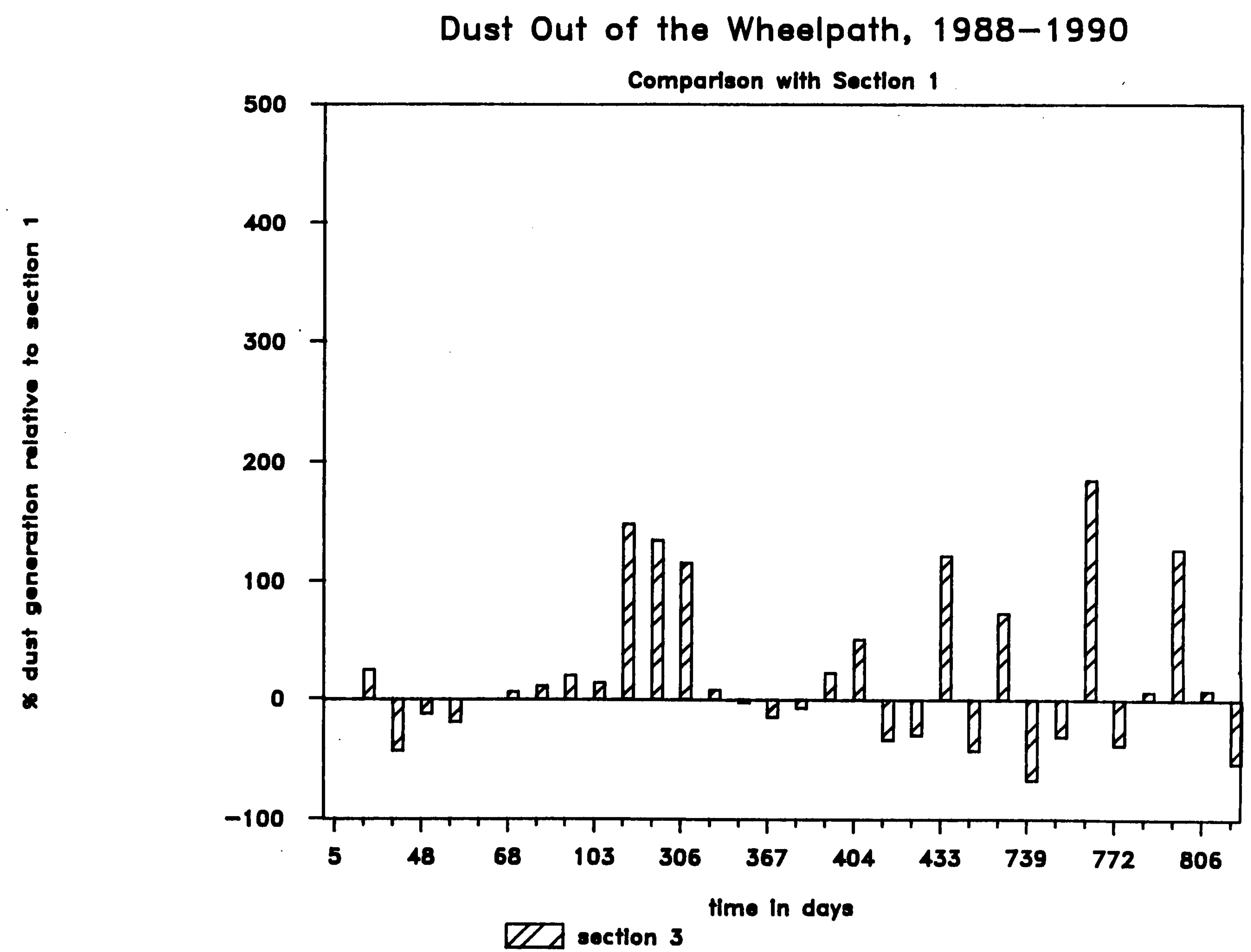

Dust from the Wheelpath, 1988-1990
Comparison with Section 1
% dust generation relative to section 1
500
400
300
200
100
0
-100
5
48
68
103
306
367
404
433
739
772
806
time in days
section 2

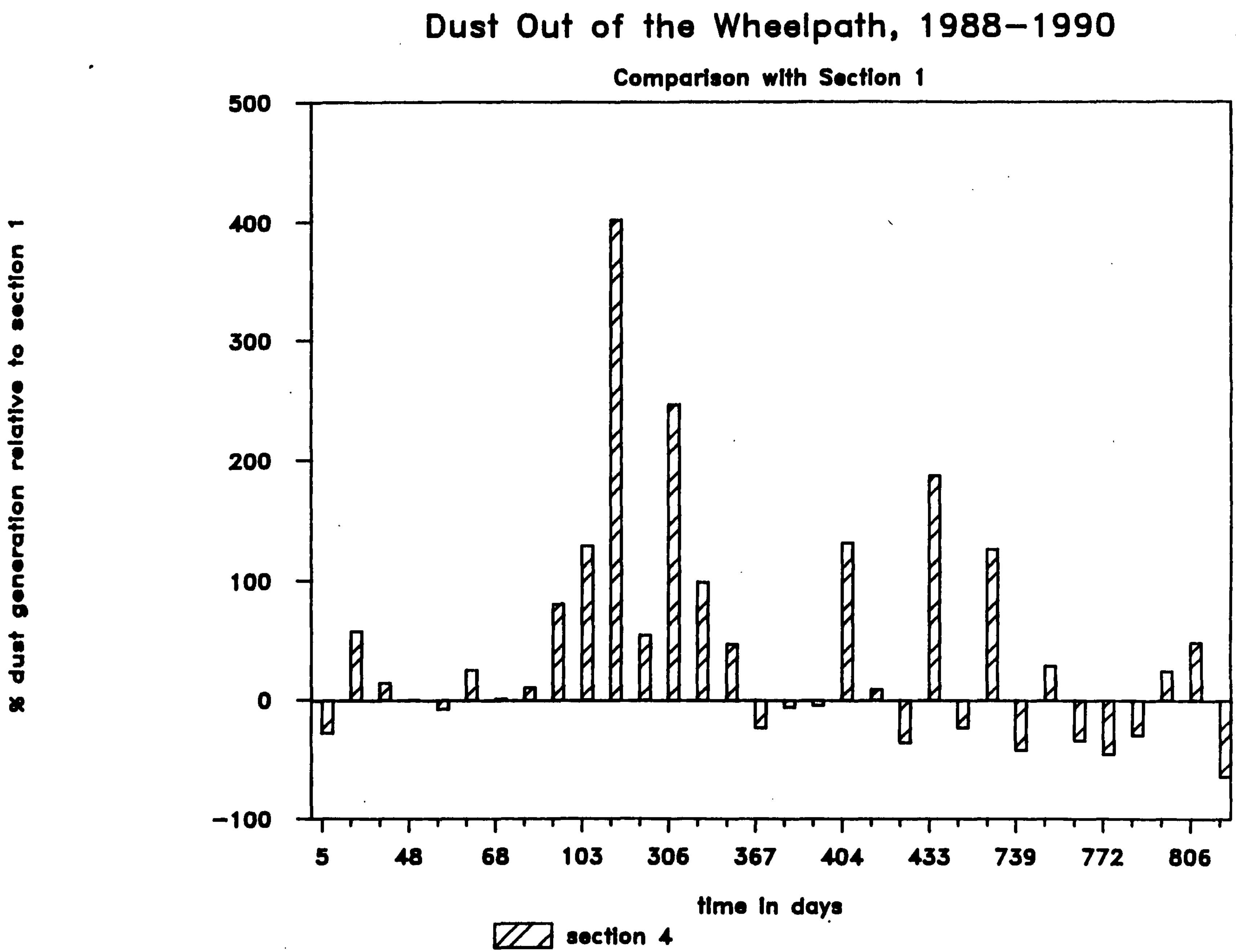

Dust from the Wheelpath, 1988–1990
Comparison with Section 1
% dust generation relative to section 1
500
400
300
200
100
0
−100
5
48
68
103
306
367
404
433
739
772
806
time in days
section 3

Dust from the Wheelpath, 1988-1990




Dust Out of the Wheelpath, 1988-1990
Comparison with Section 1
500
400
300
200
100
0
-100
% dust generation relative to section 1
5
48
68
103
306
367
404
433
739
772
806
time in days
section 2


Dust Out of the Wheelpath, 1988-1990
Comparison with Section 1
% dust generation relative to section 1
500
400
300
200
100
0
-100
5
48
68
103
306
367
404
433
739
772
806
time in days
section 3



Dust Out of the Wheelpath, 1988–1990
Comparison with Section 1
% dust generation relative to section 1
500
400
300
200
100
0
−100
5
48
68
103
306
367
404
433
739
772
806
time in days
section 4